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Development of BIM learning model for construction sites operatives

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The highest level of BIM adoption is the utilization of BIM by construction site operatives who are knowledgeable and skilled in BIM. Furthermore, the full benefits of BIM cannot be achieved without construction site operatives that are knowledgeable and proficient in BIM. Despite the creation of educational models for BIM training by colleges targeting construction professionals, there is currently no specific BIM learning model for construction site operatives. The aim of this research is to develop a BIM learning model to assist construction site operatives in their BIM transformation. The study employed a positivist philosophical research design, which required the use of a quantitative technique. The BIM learning model for construction site operatives was developed by using the SAMR (substitution, augmentation, modification, and redefinition) model, Bloom's digital taxonomy, social learning theory, and design thinking theory. The hypotheses derived from the model were analyzed using structural equation modeling. The study findings indicate that the learning standards for BIM tools, BIM technologies, and BIM skills will enable construction site operatives to effectively utilize BIM tools. The most crucial factor in learning standards for BIM tools is the implementation of substantial BIM tools to modify work processes. The findings also indicated that engaging in professional role-play and interactive assignments had the greatest influence on learning results. The research asserts that the model's implementation will improve performance and efficiency on construction sites by providing construction site operatives with the necessary abilities to proficiently utilize BIM technologies.

KEYWORDS

Bim, BIM learning model, BIM use on construction sites, BIM in construction, artificial intelligence use on construction site

1 Introduction

BIM is a system that uses interconnected processes to create, analyze, and communicate building information models (Bargstadt, 2015). BIM is important to the construction industry because it improves communication, project success, and construction safety management. BIM enables project stakeholders to collaborate more effectively and identify potential issues early on in the design phase. This ultimately leads to more efficient project delivery and reduced costs. The adoption of BIM in the construction industry has proven to be a game-changer in improving project outcomes and enhancing safety measures as it enables construction teams to better coordinate and schedule tasks, which can help prevent accidents and ensure a safer working environment for all involved. BIM also facilitates

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collaborative working and improves the quality of building information throughout the project lifecycle.

The use of BIM in building projects necessitates construction experts and site operators with BIM expertise (Chen et al., 2020). This implies that as the construction industry continues to embrace BIM technology and its associated growth and innovation, the demand for skilled professionals with BIM expertise is on the rise. Similarly, with the increasing importance of BIM in building projects, the demand for construction site operatives who are proficient in BIM is on the rise. While universities have developed educational models for BIM training aimed at construction professionals, there is currently no specific BIM learning model that targets construction site operatives to ensure that they are equipped with the necessary skills to effectively implement BIM on site (Abbas et al., 2016). BIM learning, or BIM education, refers to the acquisition of both theoretical and practical knowledge pertaining to BIM technologies, processes, and protocols (Suwal et al., 2017).

BIM implementation occurs at construction sites and is the responsibility of construction site operators. The omission of construction site operatives from BIM education has resulted in restricted BIM implementation, mostly confined to theoretical and design aspects. Construction professionals require BIM-skilled construction site operators in order to effectively transmit site-specific information and deploy BIM on construction sites (Bozoglu, 2016). The growing intricacy of construction projects and the division of construction professionals have led to a greater need for site-specific information and specialized instructions for specific tasks. Therefore, the use of BIM as a means of communication between construction professionals and construction site operatives has become essential (van Berlo and Natrop, 2015). Construction workers who possess BIM knowledge on building sites exhibit the highest level of BIM adoption, according to (Hamledari et al., 2017; Bargstadt, 2015).

Pikas et al. (2013) observed that the benefits of BIM cannot be fully achieved without building site workers who are knowledgeable and skilled in BIM. Hamledari et al. (2017) recognized the absence of data synchronization between BIM and on-site activities as the main obstacle to BIM deployment. According to Lee et al. (2013), the lack of personnel with BIM skills and expertise is a major hindrance to the use of BIM in building projects. Bargstadt (2015) asserted that construction site operations, including work directions, planning, job assessment, and work methodology, necessitate the use of trustworthy, prompt, and precise information provided by BIM. As a result, it is critical to train construction site workers on how to use BIM technologies. Construction site operatives have essential responsibilities in change management and the creation of as-built BIM, making their function critical.

Murvold et al. (2016) emphasized the need to equip construction site operatives with a comprehensive understanding of how to effectively utilize the BIM model in their day-to-day tasks. According to Brathen and Moum (2016), the reason for the restricted adoption of BIM on construction sites is the lack of BIM expertise among construction site workers. These considerations indicate that having construction site operatives who are knowledgeable in BIM is critical for effective BIM application. The use of BIM technology among construction site workers is vital for enhancing their competence and marketability, increasing their job contentment and drive, and improving their efficiency. Additionally, their ability to navigate and manipulate BIM models can lead to better decision-making, cost savings, and ultimately, successful project outcomes. By investing in training and development programs for construction site operatives, companies can ensure that their workforce is equipped with the necessary skills to leverage BIM technology effectively and stay competitive in the industry.

The necessity of specific training for the construction site operatives to better use BIM potentials for facilitating safety management and construction plants and equipment maintenance operations creates the need for a BIM learning model for the construction site operatives (Fargnoli and Lombardi, 2020; Fargnoli et al., 2019). Construction site operatives face unique needs and challenges in their daily work, which requires BIM skills and knowledge. Through BIM training and education for construction site operatives, companies can ensure that their workforce is equipped to meet the demands of the digital construction industry and productivity of construction projects.

The aim of this research is to create a BIM learning model to facilitate the adoption of BIM by construction site operatives. The term “construction site operatives” in this study will encompass construction managers and workers, including site managers, site supervisors, site engineers, site officers, and craftsmen, who are actively involved in carrying out construction projects on construction sites. The project aims to determine the most effective BIM learning model for construction site operatives to acquire BIM tools, technologies, and abilities, enabling them to use BIM practically on construction sites. In order to investigate the research issue, the study assessed the BIM learning activities, tools, areas, and standards for construction site operatives. Additionally, the study specifically designed a BIM learning model for construction site operatives.

2 Literature review

2.1 Construction sites and BIM-competent construction site operatives

With the continuous advancement of technology, there is an increasing demand for construction site operatives to include BIM into their daily activities (Hamledari et al., 2017; Bargstadt, 2015; Murvold et al., 2016; Brathen and Moum, 2016). The need for construction site operatives who are skilled in BIM is based on the fact that it will allow them to access project data in real-time, identify and resolve problems more efficiently, and ultimately make the building process more efficient. Construction site operatives that are knowledgeable in BIM might enhance collaboration and communication among project stakeholders, resulting in improved efficiency, productivity, and cost reduction.

Empirical research from scholars has demonstrated that construction site operatives who are competent in BIM exhibit enhanced worker efficiency compared to those who are not competent in BIM (Shahruddin et al., 2021). According to these experts, construction site operatives who were skilled in BIM were able to mentally see the final design and construction process, strategize safety precautions, recognize potential dangers, and establish a more unified and effective workflow. BIM-competent construction site operatives were able to utilize BIM competencies to visually evaluate jobsite conditions, identify hazards, contribute to risk assessment and planning, carry out accident investigations, and create targeted safety plans. They also established strong connections between safety concerns and construction planning (Shahruddin et al., 2021). The BIM skills possessed by construction site workers who are proficient in BIM stem from their talents in areas such as creating 3D representations, developing walk-through animations, and conducting 4D phasing simulations (Ganah and John, 2017).

Having construction site operatives who are skilled in BIM ensures that construction projects are carried out with improved efficiency and a strong emphasis on the safety and welfare of all personnel. Their presence on building sites also facilitates the implementation of BIM in construction projects. Several studies, including those conducted by Whitlock et al. (2018), (Kim et al., 2020; Dadashi Haji et al., 2023), have examined the potential applications of BIM in the context of building sites. According to Whitlock et al. (2018), BIM may be utilized for the management of construction site logistics. Lee et al. (2018) proposed a construction information database system that utilizes BIM technology to effectively handle all site information produced during the building process. Kim et al. (2020) introduced a system that utilizes BIM to automate the process of recognizing and evaluating hazards at building sites, hence facilitating risk assessment. Marzouk and Al Daour (2018) suggested that BIM can be employed to organize the evacuation of workers from building sites by utilizing BIM and agent-based simulation. In their study, Dadashi Haji et al. (2023) introduced a measuring technique that utilizes BIM to assess safety-leading indicators at building sites. Feng and Lu (2017) employed BIM to automate the process of scaffolding planning for the purpose of conducting risk assessments at building sites.

Ganah and John (2017) asserted the capability of using BIM in health and safety (H&S) planning processes on building sites. The study also presented a framework to enhance health and safety practices on-site, addressing practitioners' demands for understanding health and safety issues. Maki and Kerosuo (2015) asserted that site managers' everyday responsibilities necessitate the use of building information modeling in construction site management. Baduge et al. (2022) offered a distinctive viewpoint on the uses of artificial intelligence (AI), machine learning (ML), and deep learning (DL) throughout the whole building lifespan, encompassing the conceptual, design, construction, operational, maintenance, and end-of-life stages. Chung et al. (2023) developed a novel safety model based on the Internet of Things (IoT) to provide real-time monitoring of workers and the environment at construction sites. The proposed methodology recognized real-time staff safety issues to decrease accident rates and also archives digital data to enhance future training and the system itself.

Asgari and Rahimian (2017) came up with a new way of thinking about ontology that makes it easier for a dynamic, self-organizing sensor (agent) network to collect and share real-time data from construction sites. This platform automatically and efficiently controls intelligent agents, including virtual reality cameras, radio-frequency identification (RFID) scanners, and remote sensors, to locate, report, and document high-risk issues. Song and Marks (2019) utilized BIM as a means of facilitating project communication and automating the planning of equipment paths on a building site that is subject to constant change. In 2019, Zhou and Rezazadeh Azar developed a tool that uses BIM to analyze the environmental impact of on-site construction processes for building structural systems. This tool estimates the energy consumption and carbon emissions of the structural system, allowing for easy comparison. Dasović et al. (2019) introduced a proactive BIM strategy for work facilities and the efficient placement of tower cranes on building sites with repeated tasks. In their study, Kulinan et al. (2024) proposed a technique that combines BIM with computer vision to actively observe and identify potential safety risks for workers at building sites.

In their study, Getuli et al. (2022) developed a library of smart objects specifically designed for BIM-based construction sites and emergency management. The purpose of this library is to facilitate mobile VR safety training experiences. The researchers aimed to address the problem of a lack of organized digital content dedicated to creating VR site scenarios, which has been identified as a major obstacle in implementing BIM and VR for construction workers' safety training. Hossain et al. (2023) introduced a framework that utilizes cloud-BIM technology to enable real-time safety monitoring on construction sites. The aim of this framework is to improve safety procedures and minimize the occurrence of deaths. This system combines an automatic safety tracking mobile application to identify dangerous areas on construction sites, a cloud-based BIM system for visualizing worker tracking on a virtual construction site, and a web interface for visualizing and monitoring site safety. Braun and Borrmann (2019) introduced a new technique that utilizes 4D building information models and an inverse photogrammetry methodology to automatically assign labels to construction photographs. Despite the numerous potential applications of BIM on construction sites, its implementation is severely limited due to inadequate training and a lack of effectiveness in teaching construction site operatives about BIM (Young et al., 2021). Maki and Kerosuo (2015) and Brathen and Moum (2016) argue that the utilization of BIM at building sites remains restricted due to the inadequate proficiency of construction site operatives in using BIM.

2.2 BIM learning models for construction site operatives

Developing BIM training programs for construction site operatives necessitates the use of a BIM learning framework. Nevertheless, there is a scarcity of BIM learning models specifically designed for construction site operatives, in contrast to the availability of BIM learning models tailored for construction professionals in higher education institutions (Abbas et al., 2016). Research has proposed methods for conducting BIM training and developing BIM learning models. For instance, Vestfal and Seduikyte (2024) argued that the learning models for BIM entail the identification of learning curves for building jobs with and without BIM support. These curves are then compared, and the learning effects attributed to BIM are calculated by analytical procedures. Taehui et al. (2020) suggest that BIM training programs for construction workers should prioritize safety training through the use of 3D BIM (virtual reality simulation). The suggestion was made based on the discovery that personnel who received training using BIM simulation had a superior degree of comprehension in comparison to those who received conventional training. Virtual reality was shown to be more successful than traditional lecture techniques for safety training. It emphasized the need to adjust training programs to build new skills and competencies for construction workers in BIM applications.

Alhamami et al. (2020) conducted a comprehensive investigation to identify the skills and abilities required for BIM training in the context of building energy efficiency. The findings demonstrated that BIM has the potential to facilitate the digital transformation of the construction sector in Europe through tailored BIM training and educational initiatives aimed at enhancing energy strategies with more knowledge and adaptability. This study emphasizes the need for incorporating BIM training into school curricula to ensure that upcoming professionals in the construction sector have the essential abilities to tackle energy efficiency concerns. By integrating BIM into training programs, professionals may leverage data-driven insights to enhance building performance and save energy usage. This research highlights the importance of ongoing learning and adjustment in the construction sector to meet the changing requirements of sustainable building techniques.

Ramadhan et al. (2022) fully executed a BIM training program for the WIKA Intermediate Allplan Batch 8 training series, covering all aspects from start to finish. The training program significantly enhanced the participants' understanding of BIM, enabling them to proficiently execute practical assessments using the acquired information. Furthermore, the study demonstrated that the incorporation of BIM training not only boosted trainees' comprehension of sustainable construction techniques, but also bolstered their capacity to use this information in practical situations. The training program's efficacy highlights the importance of allocating resources towards ongoing education and enhancing skills in the construction sector to foster innovation and achieve long-term sustainability objectives. In order to effectively fulfill the increasing needs for energy-efficient and environmentally friendly buildings, experts must keep up-to-date with the newest technology and processes as the sector continues to advance.

In their study, Semaan et al. (2021) examined the importance of work-based education and training (WBET) requirements by creating an organizational upskilling model (OUM). The survey found a comprehensive consensus across organizations that there is a considerable need for BIM training. However, the organizational body of knowledge needs to be better publicized, as employees were not aware of its easy accessibility. OUM demonstrated that the primary factors influencing BIM adoption were mindset, user proficiency, and organizational backing. Guided by their internal culture, OUM allowed the engineering consultant in charge to anticipate the urgent WBET upskilling requirements and prepare for the necessary capital expenditure. The engineering consultant successfully aligned their training programs with the identified relevant variables through the implementation of the OUM. This ensured that staff had the essential skills and knowledge required to properly deploy BIM technology. The successful execution of the OUM demonstrated the need for investing in upskilling programs to maintain competitiveness in a swiftly changing industry.

Shojaei et al. (2023) outlined the many approaches that construction companies employ to ensure their staff and project supplier network partners have the necessary skills and training to effectively facilitate and maintain the deployment of BIM. The results indicate that major contractors who achieved success implemented an internal training plan within their businesses and fostered a collaborative approach with their project supplier network partners to facilitate mutual growth. These strategies guaranteed that all individuals involved with the projects have the required knowledge and skills to properly use BIM technology. The study emphasized the significance of collaboration between primary contractors and their suppliers to cultivate a culture of ongoing learning and growth. Construction businesses can maintain their competitiveness and respond to market changes by investing in upskilling programs and fostering a supportive learning environment.

In 2022, Sampaio and Gomes conducted a concise BIM course at the University of Lisbon. The course focused on the latest advancements in BIM and targeted architects and civil engineers from various engineering fields, as well as professionals in areas such as environment, construction, maintenance, consulting, heritage enterprises, and public organizations like city councils. The training covered a variety of topics, including conflict analysis, planning and materials takeoff, interoperability, analytics, information transfer across applications, and historic building information modeling. The training participants were able to improve their proficiency in BIM technology and effectively utilize it in practical projects, hence enhancing their efficiency and production in their respective domains. The course's experiential methodology enabled the participants to acquire practical proficiency and self-assurance in utilizing BIM software for their projects.

The suggestions provided by these researchers are valuable for customizing BIM training programs. Additionally, they propose that the adoption of the BIM learning model is essential for enhancing the efficiency and effectiveness of construction site operators in the implementation and utilization of BIM on construction sites. A specialized BIM learning model designed for construction site operators will help them become acquainted with construction jobs prior to commencing on-site. It will serve as a means of communication among them and provide a lifetime BIM education platform. Nevertheless, there has been a lack of initiative in creating a BIM learning model specifically designed for construction site operatives. The learning effects of this model enable building site personnel to have a deeper understanding of the real benefits that BIM can offer. The model will not only function as a training tool for construction site operatives, but it also emphasizes the significance of using BIM technology on construction sites (Hossain et al., 2023; Kulinan et al., 2024). The development of BIM applications on construction sites necessitates the implementation of a BIM learning model for construction site operatives. This model is essential in showcasing the importance of BIM and encouraging its extensive adoption. The use of BIM may have a substantial effect on the management of building sites. It achieves this by revolutionizing existing processes and procedures, fostering the acquisition of new skills and competencies among construction professionals, and ensuring that BIM competencies are acknowledged as essential credentials and certifications for construction site operatives. Consequently, researchers have made attempts to create BIM learning models.

Clevenger et al. (2014) introduced a learning model for 3D visualization that utilizes BIM and is available in both English and Spanish. The methodology is inadequate, as it just focuses on construction safety training. The BIM learning model, as described by Chen et al. (2020), primarily focuses on the significance of curriculum creation, pedagogical design, and course delivery. The model did not encompass the educational tasks for construction site operatives. Vatin and Usanova (2019) developed a comprehensive technical approach for acquiring fundamental BIM abilities. Bozoglu (2016) introduced approaches for learning collaboration and coordination in BIM education. Succar and Sher (2014) presented a collaborative BIM learning framework designed for both existing and prospective professionals in the construction industry. Macdonald (2013) devised a four-stage collaborative framework for BIM education in the Architecture, Engineering, and Construction (AEC) fields. The BIM learning model, proposed by Olugboyega and Windapo (2019), suggests that a comprehensive understanding of manual drawing combined with proficiency in 2D and 3D computer-aided design (CAD) is essential for acquiring BIM abilities. The BIM learning models are insufficient and inadequate for training construction site operators in BIM. These models do not fully align with the requirements of construction sites and fail to adequately prepare operatives for BIM-related tasks (Casasayas et al., 2020). In addition, the models do not have mechanisms in place to cultivate and assess the BIM skills and knowledge of construction workers (Suwal et al., 2017).

The lack of information about the design and efficiency of the learning and teaching assistance for BIM capabilities of construction site operatives has been restricted due to these inadequacies (Abbas et al., 2016). Furthermore, these shortcomings have limited the BIM learning systems to conventional teaching techniques focused on the lecturer rather than learner-centered approaches or methods influenced by learning theories (Chen et al., 2020). An important problem exists in the absence of a well-defined BIM learning model that addresses technical, practical, and site-related BIM activities (Abbas et al., 2016). BIM is practically implemented on construction sites. Therefore, it may be inferred that one cannot acquire BIM skills without understanding site-specific BIM tasks. In the absence of a pragmatic and location-specific BIM education framework, the implementation of BIM would remain purely theoretical and limited to the design phase. Additionally, it would result in construction site operatives lacking the necessary skills to effectively transmit site-specific information and deploy BIM on building sites (Bozoglu, 2016). The importance of BIM-based communication between construction professionals and construction site operatives has increased due to the growing complexity of construction projects and the fragmentation of construction professionals. This has led to a higher demand for site-specific information and specific information for specialized tasks (van Berlo and Natrop, 2015).

The most crucial aspect of BIM implementation is the utilization of BIM-literate construction site operatives to apply BIM directly on site. This has been recognized as the most effective way to adopt BIM, as supported by several studies (Pikas et al., 2013; Puolitaival and Forsythe, 2016; Hamledari et al., 2017; Lee et al., 2013; Clevenger et al., 2014; Bargstadt, 2015). Pikas et al. (2013) contended that the benefits of BIM cannot be realized without building site workers who are knowledgeable and skilled in BIM (Pikas et al., 2013). Puolitaival and Forsythe (2016) agreed that the use of BIM in construction projects will have a substantial influence on construction site operations. They also noted that successfully implementing a BIM project required experts who are knowledgeable in BIM and building site operators. Hamledari et al. (2017) identified the absence of data synchronization between BIM and on-site procedures as a major obstacle to the deployment of BIM. According to Lee et al. (2013), a major challenge in implementing BIM technology in building projects is the scarcity of people with BIM expertise and understanding. Clevenger et al. (2014) noted a widespread prevalence of digital illiteracy among construction site workers.

Bargstadt (2015) argued that construction site operations, including work directives, planning, work appraisal, and work methods, require accurate, efficient, and precise information provided by BIM. Therefore, it is essential for construction site operatives to have a thorough understanding of BIM tools for construction processes. This is vital because construction site operatives have crucial responsibilities in change management and the production of "as-built" BIM. Murvold et al. (2016) emphasized the necessity of providing construction site operatives with a comprehensive understanding of how to effectively utilize the BIM model in their everyday tasks. Kivrak and Arslan (2019) argued that errors in construction site operations have a detrimental impact on project quality, resulting in delays, cost escalation, and disagreements between the customer and contractor. To address these issues, construction personnel must have reliable access to precise information regarding construction site operations. These considerations indicate that there is a lack of study in the field of BIM regarding the development of a learning model for construction site operatives. However, it is considered to be a vital subject to explore.

2.3 Theoretical framework for the research

This study utilized the SAMR (substitution, augmentation, modification, and redefinition) model, Bloom's digital taxonomy, social learning theory (SLT), and design thinking theory to create a BIM learning model specifically designed for construction site operatives. The theory of digital taxonomy posits that in order to attain digital literacy, educational activities and resources should prioritize cognitive, emotional, and psychomotor tasks and tools (Nakapan, 2016). The cognitive task emphasizes intellectual abilities like critical thinking, problem-solving, and information acquisition. The affective task emphasizes learners' views, principles, preferences, and satisfaction. The psychomotor task involves learners' capacity to execute activities and demonstrate movement and abilities physically. SAMR is a theoretical framework that analyzes the application of technology tools within the educational sphere. The SAMR theory delineates the capacity of technology tools and platforms to facilitate educational activities, augment tasks, and permit the redefining of complex tasks. In SAMR, substitution refers to the employment of technology as a straight replacement without any functional alteration. Augmentation refers to technology serving as a direct substitute with enhanced functionality. Modification signifies that technology facilitates substantial work reconfiguration. Redefinition indicates that technology is employed to generate new activities that were formerly deemed unthinkable. The recommendations proposed by SAMR facilitate the conceptualization of BIM learning tools and technologies appropriate for the acquisition of BIM knowledge and information management competencies (Netolicka and Simonova, 2017).

SLT posits that individuals may acquire new abilities by seeing and imitating others (Rumjaun and Narod, 2020). The insights derived from SLT elucidate the influence of a learning environment that offers models and exemplars to facilitate observational learning. Design thinking is a theoretical framework that proposes an innovative and unconventional method of problem-solving (Dell'Era et al., 2020). These theories were combined to develop a comprehensive and effective learning model that catered to the unique needs and challenges faced by construction workers. The BIM learning model not only focused on enhancing technical skills but also emphasized collaborative learning, problem-solving, and critical thinking. Through the integration of these theories, this research aimed to transform traditional construction training methods and improve overall performance and efficiency on construction sites. In the model, the theory of digital taxonomy was used to propose how construction site operatives can understand how to use BIM software effectively and how to think critically about how to apply it in real-world scenarios. The theory was also used to develop a well-rounded skill set that includes problem-solving and collaboration that will benefit both workers and project outcomes.

SAMR theory was incorporated into the proposed model to postulate on how the workers can leverage technology to streamline communication, access real-time data, and improve project coordination. This integration can lead to more innovative problem-solving strategies and foster a culture of continuous improvement among the construction site operatives. As workers become more adept at utilizing technology for project management and collaboration, they can enhance their skills and adapt to the evolving demands of the modern construction landscape. SLT is incorporated into the BIM learning model to explain how the construction site operatives can learn how to effectively use BIM tools and gain a deeper understanding of how to apply these skills in real-world scenarios. Design thinking was used to postulate on how construction site operatives can approach challenges with a fresh perspective and find creative solutions through collaboration, empathy, and iterative problem-solving.

Figure 1 depicts the theoretical framework for this study, which is based on the knowledge gained from SAMR, Bloom's digital taxonomy, SLT, and design thinking theory (Nakapan, 2016; Netolicka and Simonova, 2017; Rumjaun and Narod, 2020; Dell'Era et al., 2020). The framework outlines that the BIM learning criteria for construction site operatives encompass the acquisition of knowledge and proficiency in BIM tools, technologies, and abilities. Mastering BIM tools entails the capacity to substitute manual procedures with BIM tools, enhance work procedures with BIM tools, adapt work procedures with substantial BIM tools, and redefine construction jobs with BIM tools. Acquiring proficiency in BIM technologies necessitates the capacity to generate, assess, and scrutinize BIM models, along with the ability to use, grasp, and identify BIM technologies. The acquisition of BIM skills by building site workers will be demonstrated by their proficiency in utilizing and modifying BIM (behavioral aspects), showcasing their understanding of BIM and a cooperative mindset (cognitive elements), and convincing colleagues and rivals to embrace BIM (environmental variables).

The theoretical framework led to the hypothesized relationships listed below:

H1a: There is a positive association between the learning standards for BIM tools and participation in BIM learning activities by the construction site operatives.

H1b: There is a positive association between the learning standards for BIM tools and construction site operatives' capacity to use BIM learning tools.

H1c: There is a positive relationship between the learning standards for BIM tools and construction site operatives' comprehension of BIM learning areas.

H2a: There is a positive association between the learning standards for BIM technologies and participation in BIM learning activities by the construction site operatives.

H2b: There is a positive association between the learning standards for BIM technologies and construction site operatives' capacity to use BIM learning tools.

H2c: There is a positive relationship between the learning standards for BIM technologies and construction site operatives' comprehension of BIM learning areas.

H3a: There is a positive association between the learning standards for BIM skills and participation in BIM learning activities by the construction site operatives.

H3b: There is a positive association between the learning standards for BIM skills and construction site operatives' capacity to use BIM learning tools.

H3c: There is a positive relationship between the learning standards for BIM skills and construction site operatives' comprehension of BIM learning areas.

3 Research methodology

This study employed a positivist philosophical research design to collect and analyze data using a quantitative approach. This necessitated the utilization of questionnaire surveys and statistical analysis to measure variables and draw conclusions based on empirical evidence. Through this method, the study aimed to test specific hypotheses and determine causal relationships between variables. The positivist approach prioritized objectivity and the use of scientific methods to produce reliable and valid results. A questionnaire survey was conducted on a group of construction site operatives (CSOs) in Lagos State, Nigeria. Lagos State was chosen because of its renowned status as one of Nigeria's leading hubs for building and general progress. The selection of construction site locations was deliberate, taking into account existing activities and site operators' availability. This approach ensured a diverse and representative sample of construction workers in the area. By analyzing the data collected from these specific locations, the study was able to draw more accurate conclusions and make targeted recommendations. The questionnaire survey uses a 5-point Likert

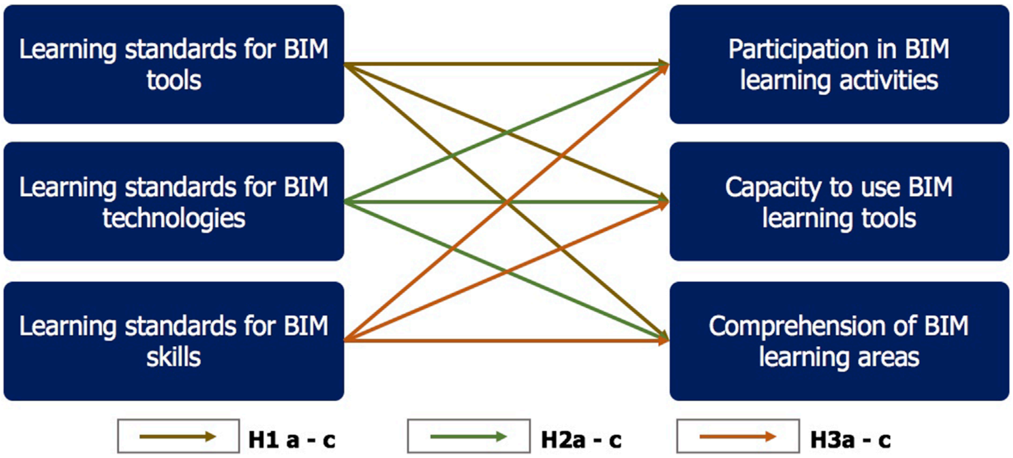


FIGURE 1
Theoretical framework for the research.

scale (where 5 stands for "strongly agree," 4 represents "agree," 3 represents "neutral," 2 stands for "disagree," and 1 stands for "strongly disagree") and was administered to a sample of 200 CSOs working on various construction projects in Lagos State.

The CSOs, which are the focus of this research, were categorized into subgroups based on their specific roles and responsibilities on building sites. These subgroups were then used to select the CSOs for further analysis. The subgroups comprise tradesmen, site managers, site supervisors, site engineers, and site officers. It was anticipated that not all of the construction sites would exhibit clusters. Given the necessity of having site managers and craftsmen as site operators on construction sites, the majority of respondents in this research were from these two categories. The survey results showed that the majority of respondents were site managers and tradesmen, reflecting the importance of their roles on construction sites. The data collected from these key stakeholders provided valuable insights into the practices and challenges faced by CSOs in the construction industry. By focusing on these specific subgroups, the research was able to target the individuals directly involved in day-to-day operations on construction sites, ensuring a comprehensive understanding of their experiences and perspectives.

The profile of the respondents was analysed based on important demographics such as educational background, designation, trade, project involvement, experience, and degree of BIM abilities (see Figure 2). A grand total of 278 questionnaires were successfully completed, with little missing data. The response rate achieved was 89.7%. This high response rate indicates a strong level of engagement and interest from participants in the study. It also suggests that the data collected is likely to be representative of the larger population of construction sector professionals. A careful analysis of the profile of the respondents indicated that the study can better understand the perspectives and experiences that informed their responses to the questionnaire survey questions. This in-depth analysis provided valuable insights that can be used to drive positive change and improvements within the industry. The proportion of respondents with a university degree was 76.72%, compared to 15.38% with a polytechnic degree. The majority of the respondents consist of managers, accounting for 46.15% of the total. Directors come in a close second, making up 30.77% of the respondents. Technical officers make up just 15.38% of the total. Overall, the demographic breakdown of the respondents indicates a well-educated group predominantly made up of managerial and directorial roles within the industry. This suggests that the insights and perspectives gathered from the survey are likely to be from individuals with significant experience and knowledge in their respective fields. These demographics provided a more nuanced understanding of the industry landscape.

The majority of the respondents (46.15%) are involved in concrete works, while around 8% of the respondents are engaged in civil engineering, building construction, site supervision, site engineering, and electrical works, respectively. These specific areas of expertise indicate that the survey results are reflective of professionals who have hands-on experience in various aspects of the construction industry. By delving deeper into the data provided by these individuals, the study was able to develop targeted solutions and recommendations that are tailored to the specific needs of different segments within the industry. The respondents have done less than 50 projects (69.23%) and between 51 and 200 projects (23.08%). Approximately 39% of the participants have accumulated 6–10 years of experience, while 30.77% and 15.38% have accumulated 11–15 years and 21 years and above of experience, respectively. 46.15% of the respondents possessed a high level of BIM abilities, whereas 30.77% had an average level of BIM skills, and 15.38% had a very high level of BIM skills. The responders' profiles demonstrated their competence and credibility in comprehending the questionnaire's inquiries and offering valuable insights. The data collected from the respondents showed a diverse range of experience levels and skill sets when it comes to BIM. It is evident that a majority of the participants have a significant amount of project experience, with a large portion also possessing high levels of BIM abilities. This indicates that the respondents are well-equipped to provide informed and valuable responses to the questionnaire,

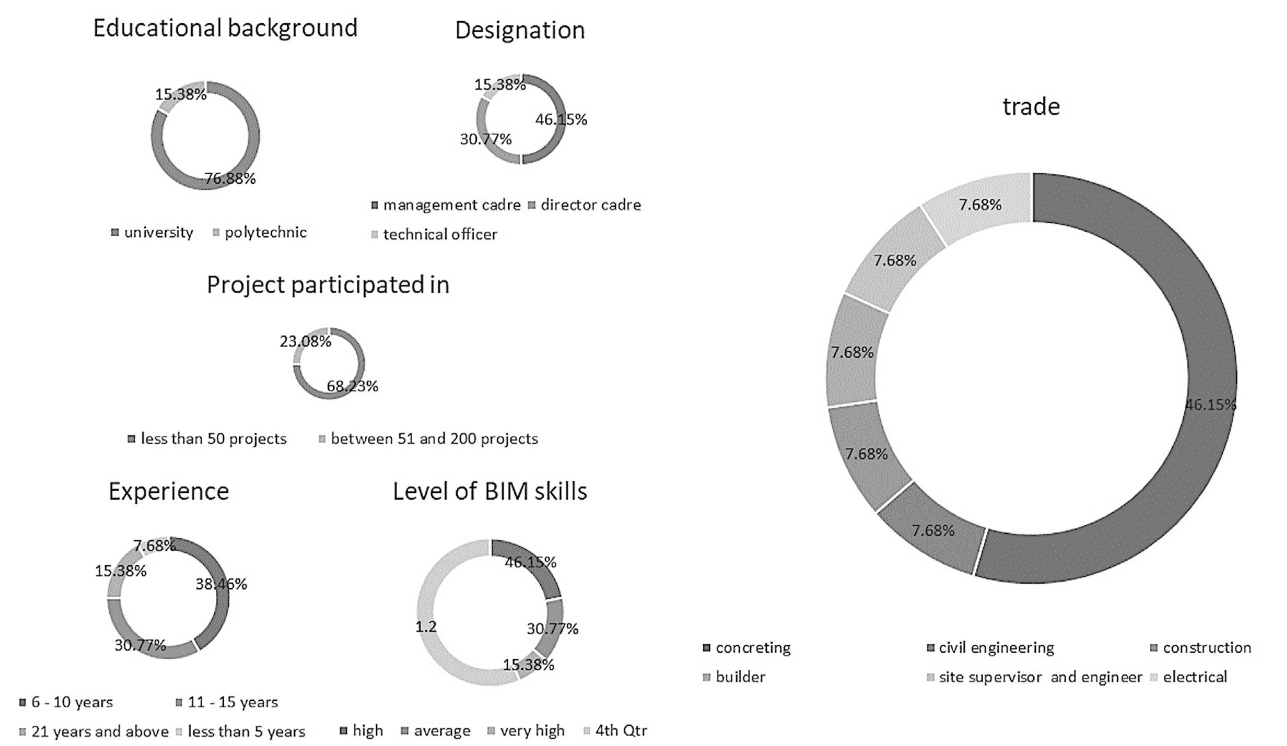


FIGURE 2
Profile of respondents.

further solidifying the credibility of the insights gathered from this study.

The questionnaire was created to gather information about BIM learning activities, tools, and areas of focus for construction site workers, as well as BIM learning criteria for these workers. The questionnaire included questions aimed at gathering information about various BIM learning activities, such as BIM implementation case studies, professional role-playing, in-class gamification, open lab activities, interactive assignments, and presentations. The respondents provided detailed feedback on their experiences with these learning activities, highlighting the effectiveness of certain methods over others. They also expressed their preferences for hands-on training and interactive learning opportunities to enhance their understanding and retention of BIM concepts. The diverse range of responses from construction site workers has provided valuable insights that will inform the development of tailored BIM learning models for this specific audience. The questionnaire gathered information on BIM learning tools by asking questions on several aspects, including BIM knowledge apps, BIM site apps, BIM-related graphics, BIM-related videos, BIM authoring and presentations, and BIM-related research. Examples of questions in the questionnaire include: "Indicate your level of agreement regarding the BIM learning activities that construction site workers must engage in to gain knowledge of BIM tools, technologies, and skills"; "Indicate your level of agreement concerning the BIM learning tools that construction site workers should master to obtain BIM knowledge and capabilities"; and "Indicate your level of agreement about the BIM learning domains essential for construction site workers to achieve proficiency in BIM tools, technologies, and competencies."

The questionnaire also inquired about many aspects of BIM learning, including proficiency in BIM interpretation, discipline-specific BIM interpretation, use of virtual reality and augmented reality, implementation of digital fabrication, and conducting design reviews. The acquired data were analyzed using both normalized z-score and structural equation modeling techniques. The tools used for the analysis were statistical package for the social sciences and Onyx. Onyx is software for graphical-based structural equation modeling. Researchers extensively utilize it to examine intricate interactions among variables (Boker et al., 2023). Onyx features an intuitive interface and robust statistical tools, enabling users to efficiently design and estimate models, test hypotheses, and display outcomes (Boker et al., 2023; Olugboyega and Windapo, 2022). Researchers depend on Onyx for precise and dependable outcomes in their investigations, proving it an indispensable instrument in structural equation modeling.

4 Results

4.1 BIM learning activities, tools, and areas for the construction sites operatives

The BIM learning activities, tools, and areas that pertain to construction site operatives were investigated using nineteen

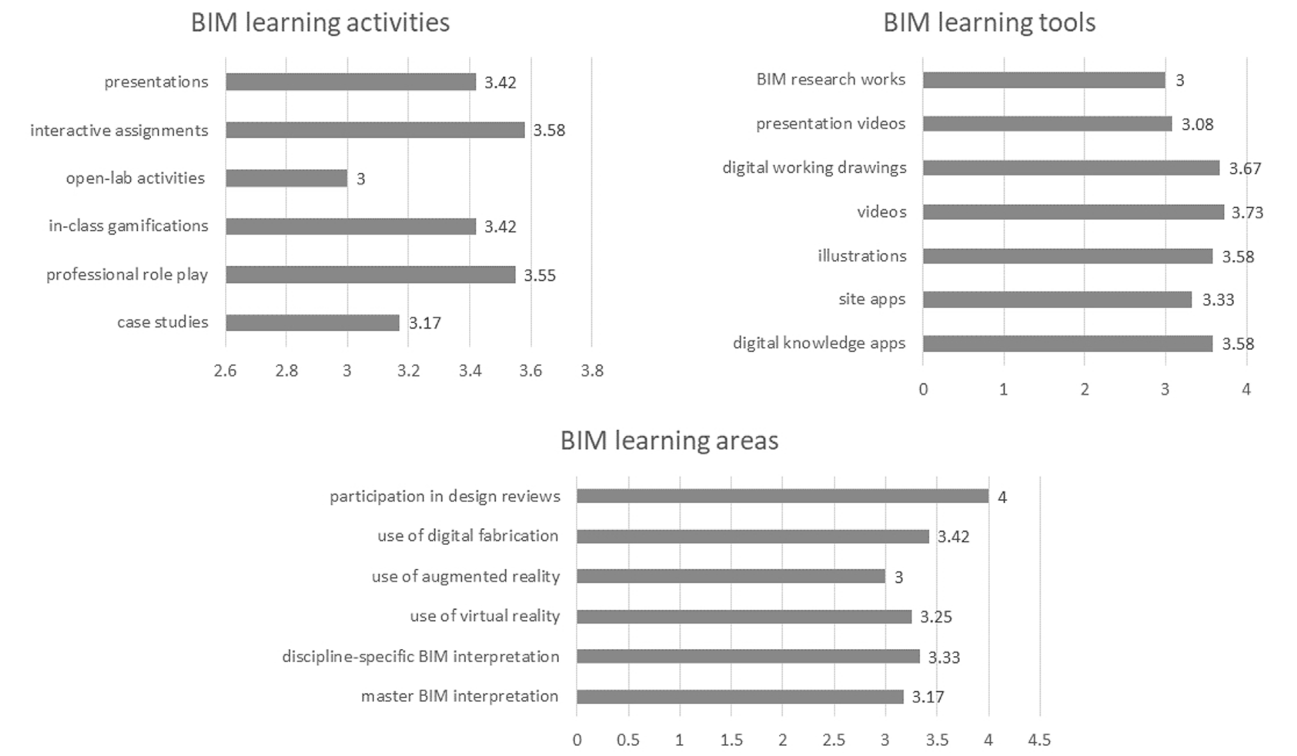


FIGURE 3
BIM learning activities, tools, and areas for the construction sites operatives.

variables. Six variables were used for BIM learning activities, seven variables were employed for BIM learning tools, and six variables were used for BIM learning areas. The average Cronbach alpha of 0.8 confirmed the reliability of the variables. The high reliability of the variables further supports the validity of the research findings, indicating that the study's results are robust and credible. The responses to the variables were analyzed using the mean item score (see Figure 3). As shown in Figure 3, only professional role play (mean score = 3.55) and interactive assignment (mean score = 3.58) had high significance among the variables for BIM learning activities. Others had moderate significance. These results suggest that both professional role play and interactive assignments are particularly effective in enhancing BIM learning areas. The high mean scores indicate that respondents found these activities to be engaging and beneficial in the learning process. The moderate significance of the other variables implies that while they may still contribute to learning outcomes, they may not have as strong an impact as professional role-play and interactive assignments. Overall, the study's findings highlight the importance of incorporating interactive and hands-on activities in BIM education for optimal learning outcomes.

Regarding the variables for BIM learning tools, four variables had high significance: digital knowledge apps (mean score = 3.58), illustrations (mean score = 3.58), videos (mean score = 3.73), and digital working drawings (mean score = 3.67). Site apps (mean score = 3.33), presentations (mean score = 3.09), and BIM research works (mean score = 3.00) had moderate significance. The result indicated that construction site operatives will respond well to videos and digital working drawings, suggesting that incorporating these tools into BIM education can enhance the learning experience. However, site apps, presentations, and BIM research works were deemed to have moderate significance, indicating that they may not be as effective in facilitating BIM learning. This highlights the need for educators to focus on utilizing digital knowledge apps, illustrations, videos, and digital working drawings for optimal learning outcomes in BIM education. By prioritizing these tools, educators can ensure that construction site operatives are actively engaged and able to develop the necessary skills for success in the field. Among the variables for BIM learning areas, participation in design reviews (mean score = 4.01) had high significance, while others had moderate significance. This suggests that hands-on, practical experiences, such as participating in design reviews, play a crucial role in enhancing BIM learning. Educators should consider incorporating more interactive and collaborative activities that allow construction site operatives to engage directly with BIM technology and processes.

4.2 BIM learning standards for the construction sites operatives

The BIM learning standard for construction site operatives was conceptualized as learning standards for BIM technologies, BIM tools, and BIM skills. Fourteen variables were used to measure the BIM learning standards. The average Cronbach alpha for the variables is 0.87. Five variables describe learning standards for

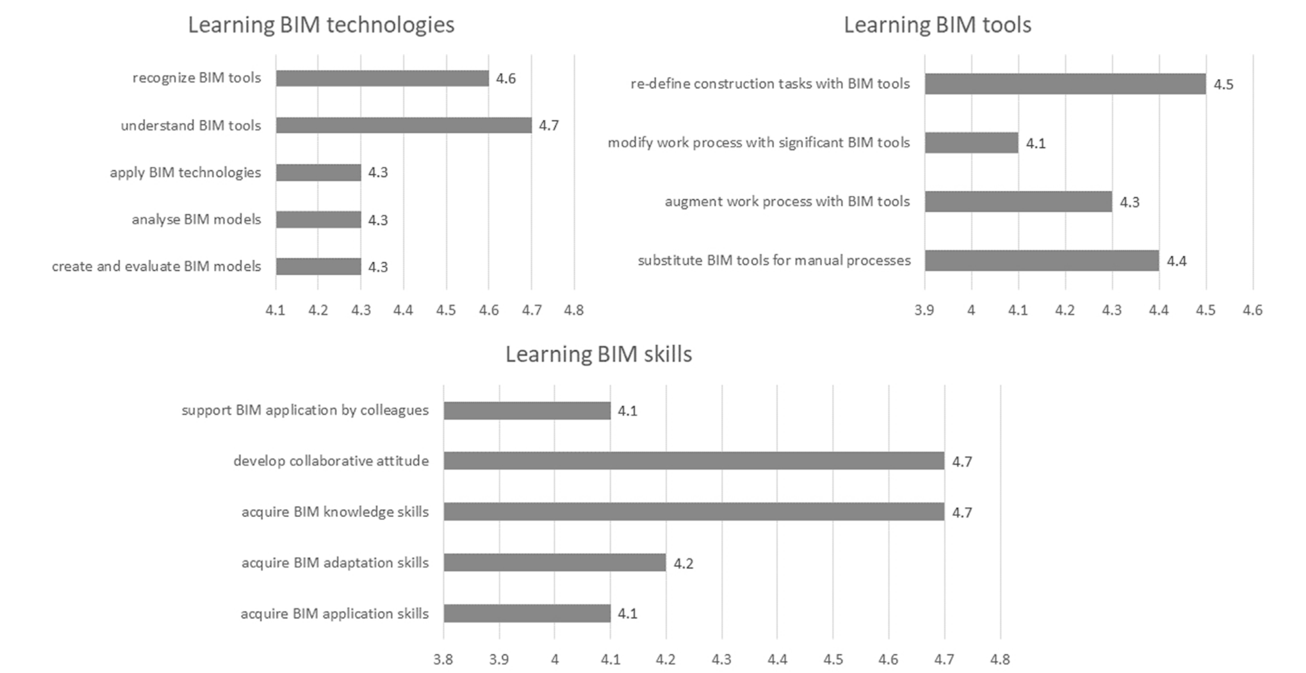


FIGURE 4
BIM learning standards for the construction sites operatives.

BIM technologies and skills, respectively. The learning standard for BIM tools was operationalized using four variables. Figure 4 presents the results of the mean score analysis for the data collected from the respondents. As presented in Figure 4, all the variables measuring the learning standards for BIM technologies had very high significance (that is, a mean score of 4.3 and above). Only two variables [acquire BIM knowledge skills (mean score = 4.70) and develop a collaborative attitude (mean score = 4.70)] had very high significance among the variables measuring the learning standards for BIM skills. The other three variables had high significance. Among the variables measuring the learning standards for BIM tools, only one variable [modify the work process with significant BIM tools (mean score = 4.10)] had high significance. The other three variables had very high significance as well. Overall, the study found that acquiring BIM knowledge skills and developing a collaborative attitude were the most important factors in learning BIM skills. These two variables were rated with very high significance, indicating their crucial role in mastering BIM technologies. Additionally, modifying work processes with significant BIM tools emerged as the most important variable in learning standards for BIM tools, with a high significance rating.

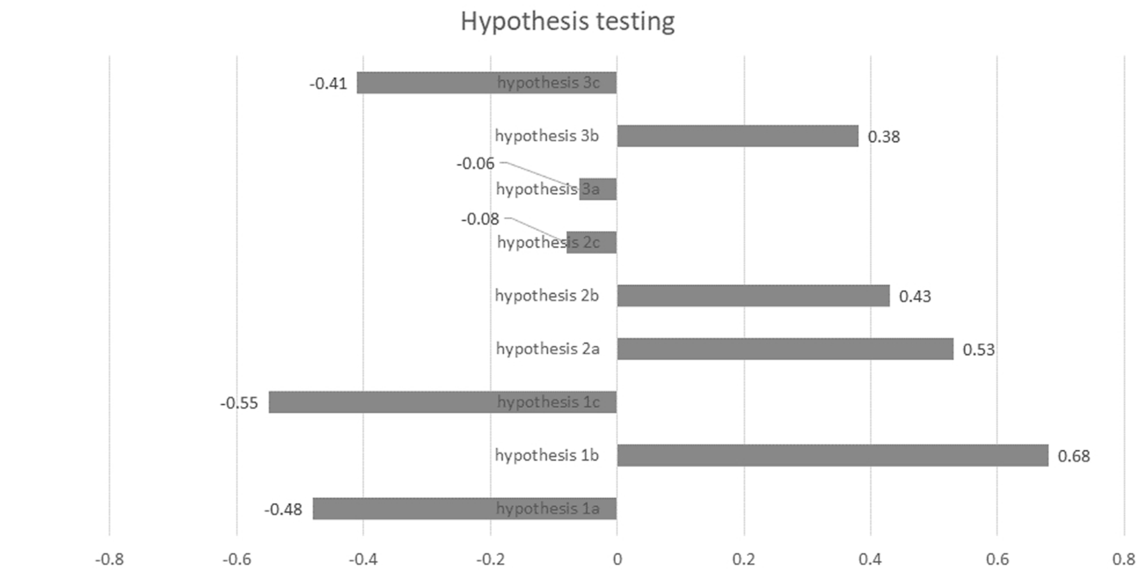
4.3 BIM learning model for construction sites operatives

To develop a BIM learning model for construction site operatives, the framework that was developed in Figure 1 was subjected to structural equation modeling analysis in order to test the hypothesized relationships in the model. Figure 5 presents the results of the structural equation modeling analysis for the hypothesized relationships. The results presented in Figure 5 revealed that all three hypotheses were partially validated. In hypothesis 1, only sub-hypothesis 1b was validated, as it was in the direction that was hypothesized in the model. In hypothesis 2 and hypothesis 3, only sub-hypothesis 2a, sub-hypothesis 2b, and sub-hypothesis 3b were in the hypothesized directions. The other sub-hypotheses (1a, 1c, 2c, 3a, and 3c) were in the negative direction. In terms of strength, sub-hypothesis 1b had a strong significance, sub-hypothesis 3b had a weak significance, and sub-hypothesis 2a and sub-hypothesis 2b had a moderate significance. These results validate that some of the path analyses that were hypothesized in the structural equation model were positive and statistically significant. The overall model fit was deemed acceptable. Overall, the findings from the analysis suggest that there is support for certain relationships proposed in the structural equation model. The significant results for sub-hypotheses 1b, 2a, 2b, and 3b indicate that there is a strong connection between certain variables. While some sub-hypotheses did not show the hypothesized direction, the overall model fit was still considered acceptable. These results provide valuable insights into the relationships between the variables under study and support the validity of the proposed model.

5 Study outcomes and BIM learning model development

5.1 BIM learning activities, tools, and areas for the construction sites operatives

The findings of this study suggest that professional role-playing and interactive assignments are effective methods for facilitating



	hypothesis 1a	hypothesis 1b	hypothesis 1c	hypothesis 2a	hypothesis 2b	hypothesis 2c	hypothesis 3a	hypothesis 3b	hypothesis 3c
■ coefficient	-0.48	0.68	-0.55	0.53	0.43	-0.08	-0.06	0.38	-0.41

FIGURE 5
Structural equation modeling analysis for the hypothesized relationships.

the learning of BIM among construction site operatives. This discovery is corroborated by the conclusion reached by Taehui et al. (2020) and implies that construction site operatives would highly appreciate experiential learning and real-world implementations of BIM in their BIM education. The emphasis on involvement in design reviews highlights the value of collaborative and practical project experiences in increasing knowledge and abilities in BIM. In the future, it may be beneficial for educators to highlight the inclusion of design reviews as a crucial element of the BIM learning curriculum for construction site operatives. This will guarantee that construction site operatives get a more profound comprehension of the design process and the art of effectively communicating with designers and engineers. By incorporating construction site operators in design reviews, educators may establish a connection between theoretical knowledge and practical application, enabling construction site operatives to directly observe the use of BIM in real-life situations. This technique would not only augment their technical proficiency but also boost their capacity to collaborate efficiently in interdisciplinary teams. Offering practical exposure to BIM will enhance the readiness of construction site operatives for the requirements of the industry and guarantee that they possess the necessary skills to tackle the complexities of contemporary building projects. Research has demonstrated that engaging in role-playing as a method of learning has a positive impact on learners' levels of interest, comprehension of course material, and excitement. It enables learners to actively engage in the learning process, resulting in improved knowledge retention and practical application in real-world situations. Although active learning settings, such as role-playing, may require learners to make an extra effort, they have the potential to improve learning results. The outcomes of this study demonstrate that interactive assignments may significantly enhance interactivity in the BIM training of construction site operatives. It facilitates the development of interactive exercises and illustrations that can be automatically evaluated, offering learners instant feedback. This enhances their critical thinking ability and drive for independent learning, resulting in better long-term information retention and self-regulated learning.

The study suggests that digital knowledge applications, BIM graphics, BIM-related movies, and digital working drawings are effective methods for supporting the learning of construction site operatives in BIM. Based on the results of this study, involving construction site operatives in design reviews during the BIM process will provide them with a valuable opportunity to learn about BIM. This will enhance their comprehension of the project in its entirety. Moreover, the study indicates that offering construction site operatives practical training using BIM software may significantly improve their educational experience. By providing students with the opportunity to directly engage with technology, they may acquire practical skills that will be highly useful in their everyday professional tasks. Furthermore, integrating BIM training into continuous professional development initiatives helps guarantee that workers remain current with the most recent technological breakthroughs and industry best practices. Furthermore, allocating resources to enhance the education and training of building site workers in BIM would result in enhanced project efficiency and superior project outputs.

5.2 BIM learning standards for the construction sites operatives

The study reveals that the learning criteria for construction site operatives in BIM technologies encompass the abilities to create and evaluate BIM models, analyze and apply BIM models, as well as grasp and recognize BIM tools. This implies that the successful installation and usage of BIM technology relies on the adaptation of work processes to properly employ BIM tools. Moreover, it is imperative for construction site operatives to receive training in BIM technologies in order to comprehensively comprehend and effectively apply these tools. Workers may enhance productivity, precision, and communication on construction projects by acquainting themselves with BIM software and procedures. In order to remain competitive and satisfy the requirements of contemporary building projects, it is crucial for construction site operatives to use BIM technology and receive the appropriate training. When training construction site operatives on BIM, the necessary learning standards for BIM tools involve replacing manual processes with BIM tools, enhancing work processes with BIM tools, adapting work processes with important BIM tools, and redefining construction tasks with BIM tools. These guidelines will guarantee that construction personnel can efficiently employ BIM technology to optimize their labor and improve project results. By incorporating BIM technologies into their workflow, construction site operatives may enhance collaboration, minimize mistakes, and enhance overall project coordination. By receiving enough training and effectively implementing BIM technology, construction site workers may continuously develop and adjust to the dynamic nature of contemporary building projects.

Based on the results of this study, construction site operatives need to possess BIM application skills, BIM adaptation skills, and BIM knowledge skills in order to be considered proficient in BIM. In addition, they must have cultivated a cooperative mindset and acquired the skills to assist their peers in their endeavors to use BIM. In addition, it is essential for them to possess the capacity to proficiently communicate and collaborate with their other team members. By acquiring proficiency in these abilities and adopting these attitudes, construction site operatives may seamlessly incorporate BIM technology into their work process, leading to enhanced efficiency and cost-effectiveness in construction projects. Proficiency in navigating intricate BIM software and effectively collaborating with team members will eventually result in enhanced project outcomes and heightened client satisfaction. With the ongoing progress in the construction industry and the growing use of BIM on construction sites, it is crucial to recognize the significance of BIM skills for construction site operatives (Whitlock et al., 2018; Lee et al., 2018; Kim et al., 2020; Marzouk and Al Daour, 2018; Dadashi Haji et al., 2023).

5.3 BIM learning model for construction sites operatives

The envisioned BIM learning model for construction site operatives has been recognized as the validated model based on the confirmed assumptions in the data. The validated model, depicted in Figure 6, elucidates that the learning standards pertaining to BIM tools, BIM technologies, and BIM skills will equip construction site operatives with the ability to utilize BIM tools. This capability will eventually improve their productivity and effectiveness on building sites. The model further posits that ongoing training and growth in BIM will result in an elevated degree of competence and expertise in utilizing these technologies. In general, the adoption of this BIM learning model emphasizes the significance of investing in training and education for construction site operatives to stay abreast of technical changes in the sector. The model further elucidates that the learning requirements for BIM technologies will serve as a catalyst for construction site operatives to engage in BIM learning activities. The model is beneficial for instructing construction site personnel on the implementation of BIM at construction sites. Consequently, construction workers will have improved skills to properly employ BIM systems, resulting in enhanced efficiency and productivity in building projects. Construction organizations may maintain a competitive workforce by investing in ongoing training and development in BIM.

Implementing this BIM learning model would not only enhance the performance of individual construction site workers but also yield significant advantages for the construction industry as a whole, such as enhanced project results and a decreased occurrence of mistakes. The model is also valuable in comprehending the learning criteria for cultivating the BIM proficiencies of construction site operatives. The concept has the potential to enhance overall efficiency and safety at building sites. Consistent investment in BIM training may result in a workforce that is more proficient and well-informed. Consequently, this can lead to improved project outcomes and a reduction in expensive errors. By establishing uniform BIM skills across construction site workers, organizations can guarantee that all team members are operating at a consistent and advanced level of expertise. Consequently, this leads to enhanced productivity and security on building sites, which is advantageous for both laborers and the construction sector as a whole. The BIM learning model aims to facilitate the actual use of BIM on construction sites, with the objective of facilitating the transition of construction site operatives towards BIM. Construction site operators can get BIM tools, technologies, and abilities by actively participating in BIM learning activities, utilizing BIM learning tools, and understanding BIM learning domains. This will enable the construction site operatives to attain their objective of acquiring proficiency in BIM tools, technologies, and competencies. Case studies, professional role-playing, in-class gamification, open-lab activities, interactive assignments, and presentations are examples of BIM learning activities that can impact the development of new skills among construction site operatives. These skills include social interaction, work interaction, risk sharing, and communication. Additional BIM learning activities encompass professional role-playing and open-lab activities. These exercises offer tangible experiential learning opportunities that can assist construction site workers in comprehending the efficient utilization of BIM tools and technology in realistic situations. By engaging in interactive assignments and presentations, construction site operatives have the opportunity to enhance their communication skills and acquire the ability to cooperate proficiently with fellow team members.

6 Practical findings, conclusions, and implications

This study presents a BIM learning approach specifically designed for construction site operatives. The model confirms the significance of ongoing training and advancement in BIM tools,

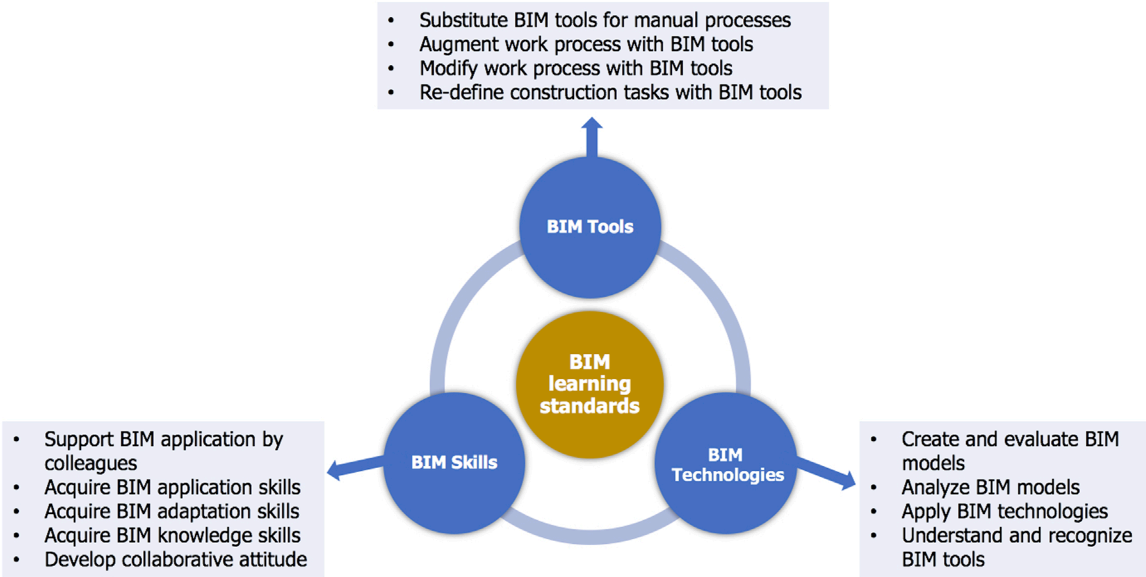


FIGURE 6
BIM learning model for construction site operatives.

technologies, and abilities for construction site operatives. The objective is to optimize performance and productivity on building sites by providing construction site operators with the requisite expertise to proficiently utilize BIM technologies. The model facilitates the practical implementation of BIM on construction sites, with the goal of transforming construction site operatives through BIM adoption. The main objective of this model is to enhance the skills and knowledge of construction site workers in BIM, with the aim of increasing efficiency and safety at building sites. The BIM learning activities encompass case studies, professional role-playing, in-class gamification, open-lab activities, interactive assignments, and presentations, as outlined in the model. BIM learning tools encompass a range of resources, such as BIM knowledge applications, BIM site applications, BIM-related visuals, BIM-related films, BIM authoring and presentation tools, and BIM-related research materials.

The BIM learning model for construction site operatives, as outlined in this study, encompasses many aspects of BIM learning. These include design review, comprehensive understanding of BIM, discipline-specific understanding of BIM, utilization of virtual and augmented reality, and implementation of digital fabrication. The model suggests that BIM training for construction site workers should include a range of learning styles and preferences and involve practical training, interactive workshops, and real-life situations. In order to maintain a competitive workforce and stay up-to-date with industry developments, it is important to provide continuing assistance and resources to construction site operatives for the continuous improvement of their BIM abilities.

The BIM learning model for construction site operatives, as developed in this study, enhances knowledge by facilitating the acquisition of BIM skills, the extensive adoption of BIM in construction projects, and the fundamental capabilities of BIM learning tools in the re-planning of capacity development for construction site operatives. As a result, construction site operatives will gain knowledge of BIM, resulting in improved productivity, innovation, and their contribution to the construction of resilient and sustainable infrastructure, as mandated by Goal 9 of the Sustainable Development Goals. The findings of this research are significant as they will enable construction site operatives to effectively utilize BIM. They will demonstrate their proficiency in utilizing BIM to monitor metallic formworks on construction sites, utilizing site survey points for mixed reality BIM visualization, employing BIM-assisted object recognition for autonomous robotic assembly of separate structures on-site, and integrating inverse photogrammetry and BIM to automatically label construction site images for machine learning.

This research is remarkable due to its provision of practical techniques to promote the use of BIM by construction site operatives. Additionally, it identifies new research areas for academics to explore. Previous studies have mostly focused on the limited potential application of BIM on building sites, in contrast to other areas. The study's conclusions have a substantial influence on the levels of entrepreneurship, productivity, and competitiveness among construction site operatives. The construction industry requires a workforce that is continuously taught and educated, self-motivated, adaptable, and capable of embracing change in order to remain competitive on a global level. The study's findings will contribute to reducing the risk of expensive mistakes and delays at building sites. This will be achieved by enhancing the construction site operatives' understanding of the intended structure, enabling them to better visualize project designs.

The research findings greatly contribute to the development of a pertinent, coherent, and efficient national strategy for educating construction site workers on BIM. Implementing an industry-focused program to enhance the BIM skills of construction site operatives would be a positive move. The results of this study will enable efficient communication of design information on building sites that utilize BIM. This will allow construction site workers to work together in integrated project delivery systems that involve several disciplines. It will be applicable in current project delivery systems, help establish shared knowledge of BIM deliverables and their needs, and assist national initiatives to promote BIM education. This research is limited as it did not explore different variables that could provide a more comprehensive understanding of the topic at hand. Without considering these factors, the study may overlook important nuances and patterns that could significantly impact the outcomes. Therefore, it is essential for future research to take a more holistic approach in order to capture the full complexity of the issue at hand.

More research is necessary to examine the many learning styles and preferences that may be integrated into a complete BIM training model for construction site operatives. A comprehensive examination should be carried out to explore how real-life situations might improve the practical implementation of BIM knowledge for construction site operatives. Future studies should examine the evaluation of the significance of continuous assistance and resources in facilitating the continual improvement of construction site operatives' BIM abilities. Future studies should consider analyzing the advantages that organizations can gain by equipping their employees with current technology and best practices through a customized BIM learning model. Additionally, it is important to examine how the BIM learning model can be adjusted to accommodate emerging technologies and industry standards like digital fabrication, 3D printing, and artificial intelligence.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Obafemi Awolowo University Ethics Committee. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

OlO: Conceptualization, Formal Analysis, Methodology, Software, Validation, Visualization, Writing–original draft. OkO: Data curation, Funding acquisition, Investigation, Resources, Writing–review and editing. AO: Data curation, Funding acquisition, Investigation, Project administration, Resources, Supervision, Writing–review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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