DEVELOPMENT OF A FRAMEWORK INTEGRATING AGENT-BASED MODELLING, BUILDING INFORMATION MODELLING AND IMMERSIVE TECHNOLOGIES FOR CONSTRUCTION TRAINING AND EDUCATION

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Abstract

Effective construction management plays a crucial role in ensuring the successful execution and completion of construction projects. However, the construction industry continues to face numerous challenges, such as time delays and cost overruns, which underscores the need to improve conventional approaches to construction management. As such, training and education are critical components of construction management. Previous research has demonstrated the potential of digital technologies, including Building Information Modelling (BIM) and immersive technologies (ImTs), in facilitating construction training and education. Similarly, agent-based modelling (ABM) has the capacity for visualisation and simulation of scenarios, thereby presenting potential applications in this area. Nonetheless, limited studies have attempted to integrate these tools to augment construction training and education. This study seeks to address this gap by conducting a systematic literature review to establish a framework that integrates the use of ABM, ImTs, and BIM for construction safety training and education. Based on the review, the framework proposes the utilisation of data derived from BIM to simulate and evaluate construction management plans through ABM. Furthermore, the results obtained from ABM could be utilised in educating construction workers through the use of ImTs. The developed framework provides a basis for future studies to examine how its performance could be enhanced through the integration of different simulation techniques, such as ABM and system dynamics (SD). Ultimately, the integration of ABM, ImTs, and BIM in construction training and education could serve as a valuable tool in improving construction management practices and addressing persistent challenges in the industry.

Keywords: Agent-based modelling; Virtual construction site; Building information modelling; Immersive technologies; Training and education

1 INTRODUCTION

It has been observed that delays in construction projects which can be referred to as the elapsed time beyond the stipulated completion date is considered a common problem in the construction industry [2][36]. It has also been observed that productivity in the construction industry has been diminishing for several years [3][36]. This therefore means that the exploration of alternative methods for managing construction projects have become essential to improve the status quo of construction projects. A key method is the application of information computer technology (ICT) tools which has been increasingly useful in the construction industry [47]. An example is the use of simulation modelling and visualisation for the planning of a construction project with the aim of improving the efficiency and performance of the project [47]. Simulation tools are very efficient and risk-free mechanisms for making decisions on construction projects as modellers could conduct virtual construction projects and evaluate their performance under various conditions and settings [35]. The outcomes of actual events or systems can be predicted through the simulation of the model of actual events or systems without spending considerable time, cost, and effort on the events or systems [19]. The different simulation techniques that can be adopted for modelling and decision making include agent-based modelling (ABM), discrete event simulation (DES) and systems dynamics (SD) [35]. Immersive technologies (ImTs) are computer technologies that have been shown to be effective in construction management, especially for training and education [42].A key area of construction management is construction training and education, and this is because it ensures the competence of construction professionals to carry out construction activities [28]. However, it has been observed that the conventional methods of training and education focuses on theories of construction management thereby making it difficult for the knowledge gained to be applied by the trainees when faced with real-world scenarios on construction site [32]. It is therefore necessary for alternative methods for training and education to be proffered in order to address the shortcomings of the conventional method of training and education. Previous studies have however shown that ABM, BIM, and ImTs are digital tools that have the potential for the training and education of construction workers by providing them with practical experience of real-world scenarios of circumstances they will face on construction site thereby addressing the limitation of the conventional methods of training and education.

At the centre of construction digitalisation, BIM generates a lot of management data from different parties in the supply chain. Meanwhile, new techniques such as ABM and ImTs have been widely implemented for construction management. However, the potential integration between ABM and ImTs using BIM data remains arguably unexploited. While it has been observed that there has been an integration of some of these technologies for construction management in literature such as integrating ImTs and BIM or ABM and BIM, the integration of all three technologies for construction management has not been explored in literature. In addition, it has been noticed that every construction project manager faces challenges as regards on-time delivery of projects, within budget, and to a required quality standard [13]. This means that there is an urgent need to develop a framework to address the issues faced by construction project managers to ensure the achievement of crucial performance indicators. With the individual benefits gained from each of ABM, BIM, and ImTs and the benefits also gained through the combination of two of these technologies such as ImTs-BIM, the integration of these three technologies is proposed to obtain enhanced benefits from the technologies as regards construction management. This study therefore conducts a systematic literature review on the applications of ImTs, BIM and ABM for construction management. The findings of the review of relevant literature were then used to develop a related framework for effective construction management through training and education.

1.1 BACKGROUND LITERATURE

ABM refers to a simulation method that is based on individual agents of which their behaviour depends on a set of rules, as well as interactions with other agents, and the environment [36][38][1]. Some software tools that have been identified for ABM are Anylogic, Pathfinder, Evac and STEPS [1]. ABM can also be referred to as agent-based simulation (ABS), agent-based modelling and simulation (ABMS), multiagent simulation (MAS), and multi agent-based simulation (MABS) [25]. The elements of agent-based models are agents (the most significant element) which could be representations of human beings or animals, the environment where the agents operate, and the rules governing the behaviour, communication, the decision-making roles and the interactions between agents and the environment [22].

The features that distinguish ABM from other modelling techniques such as DES and SD are its high regard for the heterogeneity of agents [22] and its lack of specific convention for time progression as it could either follow a continuous, discrete or a combination of both for time progression [10].The heterogeneity of agents enables precise modelling, leading to a more realistic representation of real-world scenarios of the model, especially when compared to other models with homogenous approach for agents [22]. It has also been revealed that the construction industry is characterised by heterogeneity, complexity, and variability of trade performance [31] which makes ABM a useful simulation tool in the construction industry. Overall, users of ABM can get a more realistic model with better prediction accuracy of the outcome of events, thereby offering a very effective way for managing construction projects.

Building Information Modelling (BIM) can be described as an intelligent three-dimensional (3D)-based modelling technique that provides understanding and insights on the development of more efficient building systems to Architecture, Engineering, and Construction (AEC) specialists (Uddin et al., 2021). In addition, BIM can be described as a modern approach for design and management in the construction industry and mostly contains data on all the phases of the lifecycle of a building [20]. A construction project consists of several phases which include the design phase, the construction phase which is the most complex phase and the post-construction phase which is the longest phase of a building lifecycle [34]. Examples of software tools that are used for the creation of BIM models are Autodesk Revit and ArchiCAD, and these tools create models closely approximating the actual building [39]. Other BIM-based platforms used for planning, managing, and updating of construction activities, manage documents, visualise 3D models of construction sites, and monitor the status of construction projects include Autodesk BIM 360, Oracle Latista, Dalux TwinBIM and VisiLean [31]. A 3D computerised representation of building structure containing the geometric and semantic information of the structure can be developed using BIM approach [11]. BIM promotes the effective linkage of the different building lifecycle stages, provides accurate, real-time building information [40]. In addition, BIM can be used to create comprehensive, accessible, replaceable and reliable building information for all stakeholders in an entire building lifecycle [13]. Moreover, not only does BIM maintain building information, it also improves the flow of the building information throughout the lifecycle of the construction project [46] and it can be used to coordinate heavy and fragmented data into a single model [33]. However, there are issues that can be seen as major deterrents to the implementation of BIM for construction projects including BIM versioning, misinformation as regards BIM and BIM authoring [34]. In addition, BIM models are usually developed on devices that do not have sensory components which results in no interaction between the model and the physical environment [33].

Immersive technologies (ImTs) are technologies that are used to induce the feeling of being physically present in a virtual environment through computer-generated images or avatars [7]. ImTs can also be described as the bringing together of virtual reality (VR), augmented reality (AR), mixed reality (MR), and immersive videos [7]. VR can be used to walk through an unbuilt building, test out new building design, and to present to client the exact building space [24]. AR can be described as the overlaying of computer-generated images on real scenarios such as the laying of marks in a televised football match to enhance the understanding of the match by viewers [5]. AR can be used to augment all types of human senses including senses of touch, hearing, and smell [8]. AR can also be used to add virtual objects to real environment and remove real objects from the environment in a process termed diminished or mediated reality [4]. AR are also used for entertainment, robot path planning, medical visualisation, and advertisement [8]. MR is a reality spectrum which ranges from pure reality to pure virtual reality where there is no interaction by users with the real world [27]. MR enhances the accessibility of data for better understanding of projects and for better decision making such as building design check and construction simulation and monitoring [29]. Unlike BIM-based engines, ImTs provide interactions with various construction components and an immersive experience to users [14]. While a real environment is the physical surroundings that people stand in, a virtual environment is an environment that is digitally generated with computers, lasers and light [44].

Each of ABM, BIM and ImTs have been applied for different areas of the management of construction projects in literature. Shehab et al. [36] introduced an agent-based model to act as a decision support system for construction project planners with the aim of addressing delays in construction projects which was effective for the monitoring and control of construction project. The model proved effective for the monitoring and control of construction project, and it can be used to consider unforeseen delays in projects [36]. Another study by Jung et al. [21] simulated an agent-based model to analyse various alternatives of lift systems. The study revealed that the simulation is most useful in comparing the performances of identified alternative lift systems and it is possible to derive countless number of alternatives to lift systems [21]. Ding et al. [13] developed a digital construction framework which demonstrated how project teams could improve on the management of information and organisation in renovation projects using BIM and reserve engineering. The developed framework improved the information utilisation among all the professionals in different phases [13]. Chalhoub and Ayer [9] investigated the influence of MR on the productivity and quality of electrical conduit construction and discovered that MR enabled a significantly higher productivity rate, resulted in fewer errors during the assembly process and increased the number of accurately constructed conduits especially when compared to conduits constructed with traditional paper.

1.2 RESEARCH METHODS

A systematic literature review (SLR) was conducted based on the preferred reporting items for systematic reviews and meta-analyses (PRISMA) to obtain articles related to the application of ABM, ImTs, and BIM for construction management. This study reviewed relevant journal articles because these articles are peer-reviewed and they provide a more comprehensive and higher quality information when compared to other types of publications [15][18]. Scopus database which was used to collect the relevant articles used for this study was selected as the database as this database has an extensive coverage of scientific literature [48]. The keywords used for the search were divided into two fields: the first field focused on the digital technologies while the second field focused on the construction industry. Fig. 1 shows a systematic flowchart which displays the SLR process adopted in this study. The set of search strings applied to verify the title, abstract and keyword of the articles obtained from Scopus database is as follow:

(TITLE-ABS-KEY (“Agent-based model*” OR “Building Information Model*” OR “BIM” OR “Virtual Reality” OR “VR” OR “Immersive technolog*” OR “ImT”) AND TITLE-ABS-KEY ("Construction" OR "Construction industry")

The initial search retrieved 5,939 articles from the Scopus database. The search strings were then limited to journal publications because they provide more comprehensive information on the field of study. There was no limited timeframe and articles that do not focus on ABM, BIM, and ImTs. The number of journal articles written in English language that was collected was 59 articles.

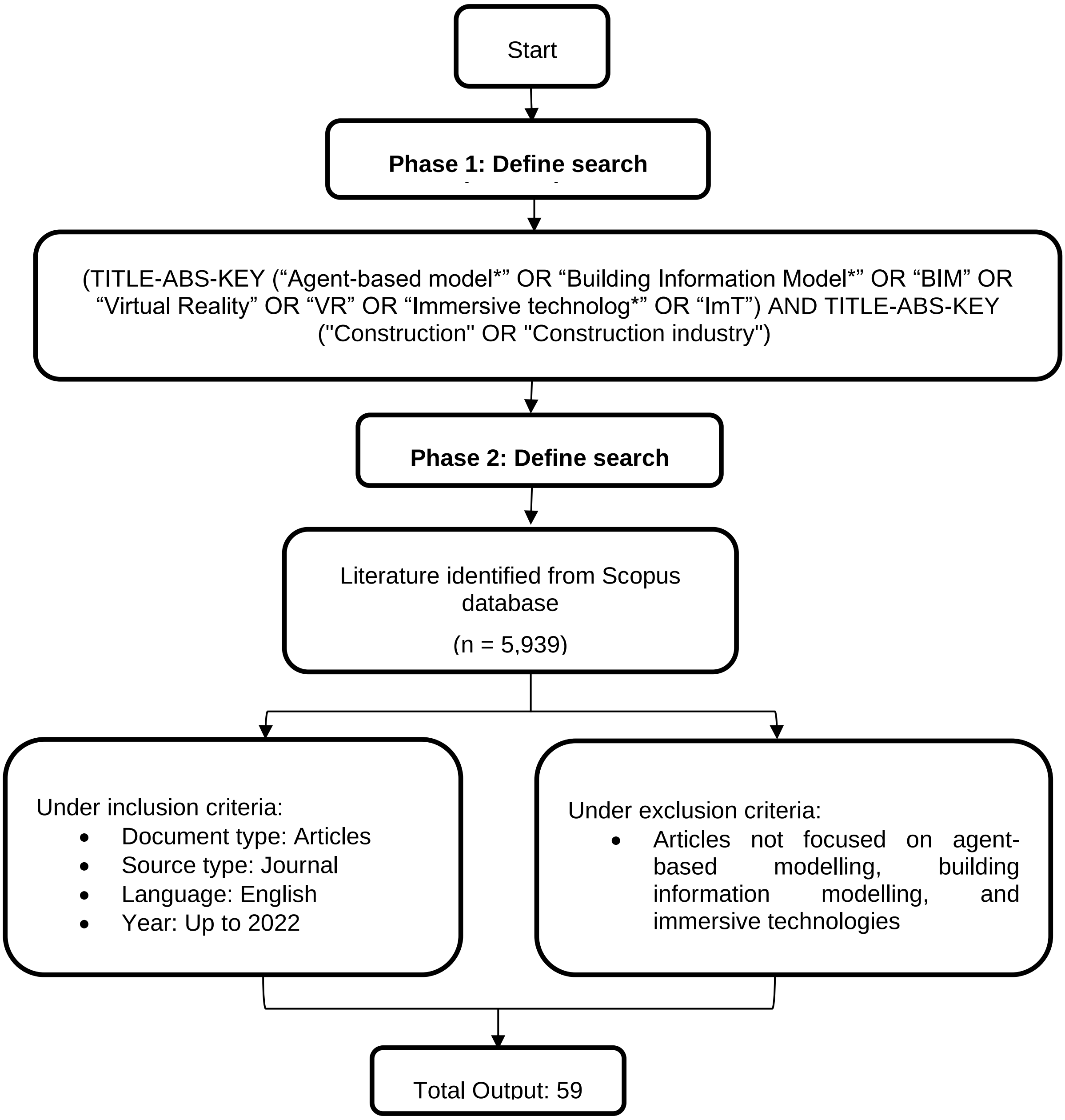

Fig. 1: Systematic literature review flowchart

An example of the many rejected articles due to lack of relevance of its contents obtained from the Scopus database is the article titled 'Virtually authentic: Graduate students' perspective changes toward authentic learning while collaborating in a virtual world' by Han & Resta [17]. The contents of this article were on the perceptions of graduate students of an online teaching and learning course which the authors argued that the construction of new knowledge by participants resulted in authentic learning from the standpoints of social constructivism [17].

1.3 RESULTS AND DISCUSSIONS

1.3.1 Integration between BIM and ImTs

To assist with construction site planning, Singh and Kumar [37] developed an AR-BIM based framework and observed that the AR-BIM improved communication among planners and enabled the understanding of future implications of the layouts proposed. Another study by Wang et al. [41], a BIM-based VR application was developed to minimise the number of assumptions during the determination of quantities from architectural drawings. The BIM-based VR application was proven to be effective in enhancing the understanding of quantity surveyors on the architectural design, efficiency of decision making and the precision in quantity surveying work by navigating the virtual 3D building model [41]. Similarly, Xie et al. [43] implemented a building information model and applied it in a VR environment to assist architects, engineers, and contractors in understanding construction projects and plans in real-time. The real-time VR simulation which was combined with radio frequency identification (RFID) and focused on steel fabrication was useful in differentiating between steel pieces, controlling the schedule of the project and to describe the entire scope of construction [43].

This study also reviewed existing frameworks for the possible combination of ABM, BIM and ImTs. An example is the framework proposed by Kim et al. [23] that integrates BIM and VR for the design phase of construction projects in order to help in making informed decisions by stakeholders. The framework provided consistent results for comprehensive evaluation criteria and metrics in a quantitative and flexible manner [23]. A framework that integrates ABM and Monte Carlo simulation (MCS) was proposed by Seresht and RazaviAlavi [35] to model the performance of construction workers, to determine the performance of a construction project as the aggregated performance of a team and to model the spread of Covid-19 on the construction site. The ABM and MCS model showed that the introduction of a few agents infected with Covid-19 can have a negative impact on the performance of the construction project [35].

1.3.2 Integration between ABM and BIM

Abadi et al. [1] used BIM to extract the spatial and physical properties of the ninth floor of a 17-storey educational building and simulated the fire effect while the evacuation behaviour of occupants was modelled through ABM with the results analysed to obtain the average and maximum required time of safe egress for various renovation alternatives. Abadi et al. [1] then discovered that the presence of fire in renovation work increased the time of evacuation in 60% of cases in fire zone of fire origin and about 40% of cases in the entire building, and it was obvious that the construction schedule with minimum cost or budget will not necessarily be the safest in all cases. As ABM can be used to obtain a realistic model with high prediction accuracy of the outcome of construction activities and BIM used to create comprehensive and reliable building information, these characteristics can be complemented with ImTs by inducing the feeling of being physically present in a construction environment into workers for effective training and education. This study has identified from the review of literature that there have been very limited studies that have focused on maximising the benefits of each of ABM, BIM and ImTs by integrating them for training and education as a strategy to improve the overall performance of construction management. Majority of practical training sessions conducted in a construction site involves oral and video instructions [45], and to a limited degree, on-the-job demonstrations. It has also been observed that the involvement of construction workers in interactive problem solving and decision-making result in higher knowledge transfer [26][30]. Technological advancements which have produced technologies such as ImTs as key interactive tools which provides an immersive experience for workers to interact with various virtual objects under various conditions has proven to be useful for the effective training of people [12][16]. As there is no framework that integrates ABM, BIM, and ImTs for construction management especially around training and education, this study proposes a conceptual framework that combines the functionalities of ABM, BIM and ImTs for construction training and education.

1.3.3 *Proposed ABM-BIM-ImTs Framework to model the management of construction projects through training and education*

The proposed conceptual framework utilises the combination of ABM, BIM and ImTs to model construction project management through training and education as shown in Fig. 2. Fig. 2 shows a flow diagram that depicts the transfer of data from BIM (e.g., Autodesk Revit) to ABM (e.g., AnyLogic software) via a Dynamo/Microsoft Excel platform.

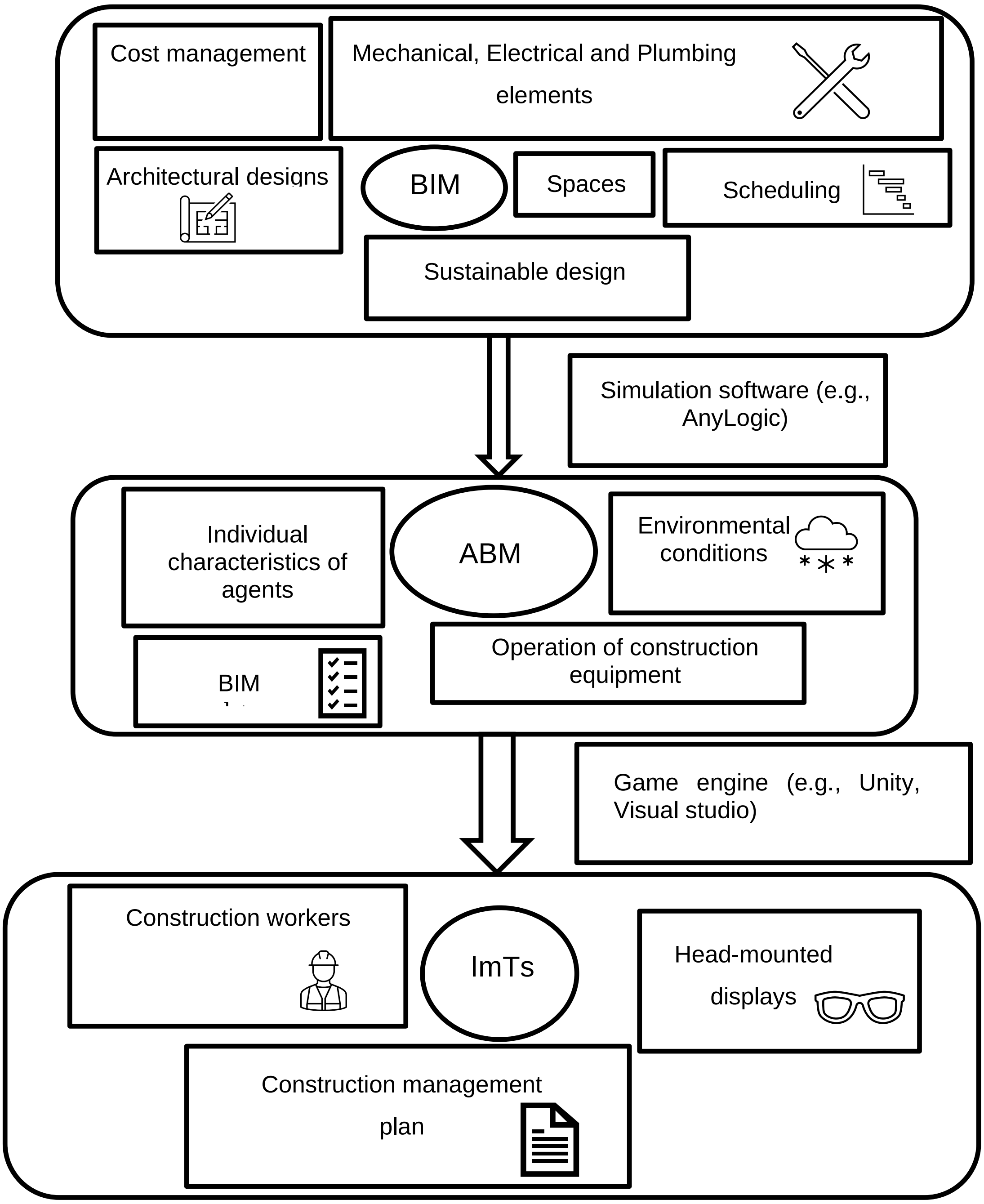

Fig. 2: Construction training and education framework integrating ABM, BIM and ImTs

The data obtained from BIM and transferred to ABM as depicted in Fig. 2 include but not limited to information on cost management, mechanical, electrical, and plumbing elements, architectural designs and scheduling. Consequently, ABM uses the data obtained from BIM for the simulation of a construction site. The simulation augments the data obtained from BIM with agents which represent the different behaviours and responses of construction workers in a construction site. It also includes different environmental conditions such as weather conditions, air quality obtained through various measuring devices such as weather thermometer to measure air temperature and operation of various tools which can affect the behaviour and reactions of agents which are elements of ABM. This is to evaluate the feasibility of the construction project and to assist with the planning of the project's scope, schedule, quality, and safety. The results from the simulation and assessment conducted using ABM is then used to educate construction workers on the planning and execution of construction works on-site with the use of ImTs. Furthermore, ImTs will be used to create the virtual construction site based on the design from BIM that has been transferred to ABM for simulation and assessment. The virtual construction site would be used for the transfer of knowledge about the developed construction management plan to construction workers. The construction workers could be educated on areas such as the various procedures to take to ensure the quality of the different facet of construction activities, the various roles, or tasks each construction works will undertake and occupational safety and health regulations. These are areas that, if not addressed properly, could lead to delay in the completion of construction projects, increase the cost in the execution of construction projects and affect the quality of job done. The construction workers will be immersed in the virtual construction site with the use of head-mounted displays (HMDs) or alternatively with projected screens and controllers in an enclosed environment.

Whilst the integration of BIM, ABM and ImTs may be beneficial for training of construction workers, the integration may come with challenges. As there are many software tools developed for each of these three techniques, the challenges of integrating the tools include the compatibility of all three tools for effective integration. It would therefore require more time and efforts to pick the best tools for each of these techniques for a particular construction project as construction projects are unique. In addition, construction professionals may not have the required skills needed to operate a tool that integrates ABM, BIM and ImTs and as such may need further skills development and training in that regard.

2 CONCLUSION

This study developed a conceptual framework for the planning of construction management to improve the execution of construction projects. The conceptual framework which integrates BIM, ImTs and ABM have a high potential to enhance the construction management through training and education. Information pertaining to the design of the construction project would be transferred to ABM via the Dynamo/Excel platform for simulation and assessment. The outcome of the simulation would drive the training and education of construction workers with the use of ImTs. Potential drawback as regards the developed framework could include the lack of adequately trained experts in the implementation of BIM, ABM and ImTs. In addition, data protection is very essential in the implementation of the framework as data from the BIM model should be protected from misuse or loss.

The study proposes that further work is done to test or validate the conceptual framework on different types of construction projects. Further work can also be done to enhance the performance of the conceptual framework by considering a different simulation technique such as integrating ABM and SD as previous literature revealed that highly dynamic factors such as temperature can be modelled very effectively with SD.

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