The Role of 5D Building Information Modelling in Construction Project Cost Management: An Overview and Future Directions

Muhammad Hadi Mustafa[1], Faizul Azli Mohd Rahim[1], Chia Kuang Lee[2]

[1]Department of Quantity Surveying, Faculty of Built Environment, University of Malaya, Kuala Lumpur, Malaysia.
[2]Faculty of Industrial Management, Universiti Malaysia Pahang, Pahang, Malaysia.

*Corresponding author: *hadimustafa@um.edu.my*

Abstract

The significance of 5D BIM in construction project cost management is increasing as the construction industry has experienced significant technological advancements. Despite the growing importance of 5D BIM in construction project cost management, there is still a lack of comprehensive understanding regarding its full potential and the necessary skills and training required by professionals in utilizing this technology. Thus, there is a need to explore the benefits, challenges, and best practices of implementing 5D BIM in cost management, as well as the role of professionals in utilizing it for optimal results. This paper aims to address this knowledge gap through a systematic literature review and provide insights into the future of 5D BIM in construction project cost management. The paper discusses the benefits, challenges, and best practices of implementing 5D BIM in cost management. Furthermore, it examines the role of professionals in utilising 5D BIM for cost management, including the necessary skills, training, and team-building strategies. Additionally, the paper delves into the future of 5D BIM in cost management, exploring emerging trends and technological advancements. The conclusion summarises the key points and highlights the insights into future research directions.

Keywords: *5D BIM, Cost management, Technology, Construction projects*

1. INTRODUCTION

Building Information Modelling (BIM) is an innovative approach for the design, construction, and management of buildings and infrastructure projects. Building Information Modelling (BIM) is a process that entails the development and utilisation of digital models that encompass comprehensive details regarding the physical and functional attributes of a project from inception to completion (Li, Shi, & Si, 2021). Building Information Modelling (BIM) is a tool that aids in the integration and coordination of diverse project disciplines. This tool allows stakeholders to collaborate more effectively and make informed decisions (Ali et al., 2018). Despite the growing importance of 5D BIM in construction project cost management, there is still a lack of comprehensive understanding regarding its full potential and the necessary skills and training required by professionals in utilizing this technology. Thus, there is a need to explore the benefits, challenges, and best practices of implementing 5D BIM in cost management, as well as the role of professionals in utilizing it for optimal results.

The following section presents an overview of Building Information Modelling (BIM), highlighting its fundamental features and

its relevance in the construction sector. According to National BIM Standard (2013), Building Information Modelling (BIM) can be defined as a digital representation of the physical and functional attributes of a facility. It serves as a shared knowledge resource for information about the project. The fundamental concept of Building Information Modelling (BIM) is to establish a unified and consistent database of project data that can be accessed by all stakeholders participating in the project. Specifically, it covers the aspects of three-dimensional (3D) geometry, spatial relationships, geographical data, quantities, cost information, material specifications, and other relevant attributes (Rui, Yaik-Wah, & Siang, 2021). BIM expands on previous Computer-Aided Design (CAD) solutions by adding intelligent data and enabling multidimensional modelling. These dimensions include time, cost, sustainability, and facility management, which are respectively referred to as the 4D, 5D, 6D, and 7D. The dimensions facilitate a thorough visualisation, simulation, and analysis of the project, leading to better decision-making and improved project results (Franco, Mahdi, & Abaza, 2015).

The emergence of 5D Building Information Modelling (BIM) has revolutionised

the construction industry by integrating cost data with three-dimensional (3D) models. According to the Construction Industry Development Board (CIDB) of Malaysia, Building Information Modelling (BIM) is among the 12 key technologies categorised as "disruptive technologies" in the Construction 4.0 Strategic Plan 2021-2025. In Malaysia, these technologies are expected to transform the construction industry in the coming years significantly (Shafei et al., 2022). Furthermore, Building Information Modelling (BIM) is widely acknowledged for its significant advantage in facilitating an automated approach to Quantity Takeoff from a three-dimensional (3D) model (Smith, 2016). Nevertheless, BIM is valuable for cost estimation, scheduling, and overall project management. The adoption rate for 5D BIM is relatively high in countries such as the United States, United Kingdom, Australia and Scandinavian countries, particularly in large-scale construction projects (Vigneault et al., 2019). Many organisations, including government agencies, have mandated using BIM in public projects.

2. LITERATURE REVIEW

2.1. Systematic Literature Review (SLR)

Systematic literature review (SLR) is a widely recognized research method that involves a comprehensive and systematic approach to identify, evaluate, and interpret all the available evidence related to a particular research question (Xiao and Watson, 2017). In this paper, a systematic literature review approach was employed to investigate the role of 5D Building Information Modelling (BIM) in construction project cost management and identify future research directions. The comprehensiveness and transparency of the review are attributed to the establishment of specific criteria and the utilization of multiple databases, which enables a wider coverage of information to be attained (Xiao and Watson, 2017). The implementation of a systematic and organised strategy in reviewing the articles served to mitigate the likelihood of bias, thereby indirectly enhancing the reliability of the findings, which can be applied for making deductive conclusions (Xiao and Watson, 2017).

The process involved a set of essential steps, which included formulating a research question, developing a search strategy, setting selection criteria, incorporating diverse sources, and ensuring relevance to the research question (Xiao and Watson, 2017). The initial phase for this research consisted of a search limited to peer-reviewed articles published in reputable journals included in either the Scopus or Web of Science

databases. These two databases are chosen because it is widely recognized due to their extensive academic databases for a variety of subjects, and the selection includes only journal articles. The keywords used in screening the relevant articles for this research are 'BIM', '5D BIM', and 'construction cost management'. Two main research questions were formulated in this study: "What is the role of 5D BIM in construction project cost management?" and "What are the current trends, benefits, challenges, and future directions?".

The second phase of the study entailed establishing selection criteria, which included defining the requirements for the inclusion of research publications. These requirements encompassed the language of the study which must be in English and the publication date span from 2014 to 2023, ensuring a recent and up-to-date review of the literature. The systematic literature review revealed that numerous authors had engaged in discourse pertaining to the same subject matter. After a comprehensive screening process and careful analysis of pertinent search terms, it was determined that a total of 194 articles on the subject had been published after 2014. Subsequently, after conducting a more in-depth assessment, it was determined that 43 articles were deemed essential to the subject matter under consideration. This assessment involved a detailed review of the content, methodology, and key findings of each paper. The full texts of the articles were put through to an additional evaluation after this process. Articles that did not align with the research question were further excluded as suggested by Kitchenham et al. (2009) guideline; leaving about 28 articles to be exactly relevant for this literature review. A research tool known as Connected Papers was also used to help visualize this process as illustrated in Figure 1. Connected Papers is a unique, visual tool to help researchers find and explore papers relevant to their field of work (Princeton, 2023).
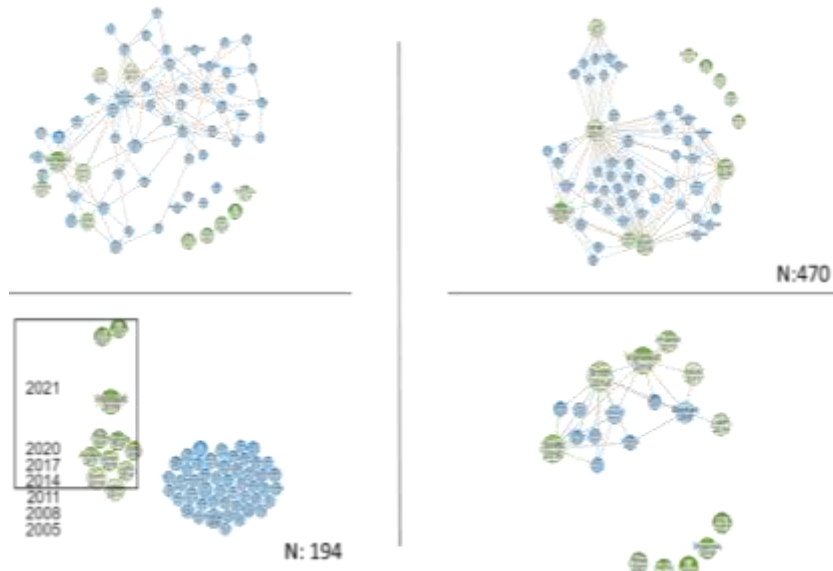
Figure 1. The process on SLR conducted.

The adopted systematic literature review approach has helped ensure objectivity and robustness in the research process. It allows researchers to identify key trends, gaps, strengths, and weaknesses in the existing literature relevant to the research question (Kitchenham et al., 2009).

2.2. 5D BIM: Cost Modelling and Management

According to Smith (2016; 2014), the goal of project cost management is to ensure that the project satisfies the required objectives in terms of financial performance. Managers, contractors, and designers oversee all parts of the project to guarantee that it is completed on time and within budget. Construction project cost management involves continuous monitoring and control of project costs from conception to completion (Musonda, 2019). This includes estimation, budgeting, forecasting, and cost control measures. The incorporation of the time (4D) and cost (5D) dimensions into BIM extends its capabilities, thereby enhancing the potential of achieving better project outcomes. Particularly, 5D BIM links cost-related information to the model, facilitating more effective cost management (Gohil et al., 2022; Ha, 2021).

Mayouf, Gerges, & Cox, 2019 (2019) explains 5D BIM as "the process of adding cost-related information to the 3D digital model to create an integrated database that facilitates cost estimation, tracking, and control throughout the project lifecycle." It involves associating cost data, such as material quantities, labour rates, equipment costs, and overhead expenses, with the

relevant components in the 3D model. (Moses, Heesom, & Oloke, 2020; Shi et al., 2020). 5D BIM offers a formidable tool for cost management by extracting quantities from 3D models. Based on literature review conducted (Moses, Heesom, & Oloke, 2020; Doan et al., 2020; Shi et al., 2020; Khosakitchalert, Yabuki, & Fukuda, 2020; Gao, Koch & Wu, 2019;) it can be deduced that the main components of 5D BIM are:

3D Geometry:

The foundation of 5D BIM is the 3D geometric representation of the project, which includes the building's physical elements, such as walls, floors, and roofs. The 3D model serves as a visual representation of the project and forms the basis for associating cost information (Musonda, 2019).

Cost Database:

The cost database can serve as a central repository for all data pertaining to costs for 3D models (Moses, Heesom, & Oloke, 2020). The document encompasses cost data related to materials, labour, equipment, and other expenses associated with the project. The database has the capability to establish a link to external cost databases or can be designed to meet the specific requirements of a project.

Quantity Takeoff:

Quantity takeoff involves extracting exact quantities of materials required for the construction project from the 3D model. This process is automated in 5D BIM, ensuring consistency and accuracy in quantity calculations (Babatunde et al., 2019). The quantities serve as inputs for cost estimation.

Cost Estimation:

Cost estimation in 5D BIM involves assigning costs to the quantities derived from the model. This can be done using predefined cost rates or customised cost databases (Babatunde et al., 2019). By associating costs with specific components in the 3D model, accurate cost estimates can be generated for the entire project or specific elements.

Cost Tracking and Control:

Once the project has started, 5D BIM enables the tracking and controlling of project costs. The cost calculations can automatically reflect changes to the 3D model or associated cost data (Musonda, 2019). This real-time tracking helps monitor cost deviations, compare actual costs against estimates, and take corrective measures as necessary.

These components make it possible for cost consultants to consider productivity allowances and price values, which results in more precise cost estimates, a lower chance of

errors, and effective financial management. Construction project cost management requires the deployment of 5D BIM in particular because it offers insights into project costs at various stages and makes it possible to take preventative action to reduce cost overruns (Moses, Heesom, & Oloke, 2020; Doan et al., 2020; Shi et al., 2020; Khosakitchalert, Yabuki, & Fukuda, 2020; Gao, Koch & Wu, 2019; Smith, 2014).

The implementation of 5D Building Information Modelling (BIM) for cost management offers a number of advantages. These advantages include enhanced precision and transparency, improved collaboration, fewer change orders and claims, faster turnaround times, and enhanced project performance (Vigneault et al., 2019; Fadeyi, 2017; Franco et al., 2015; Smith, 2014).

The utilisation of 5D Building Information Modelling (BIM) technology has the potential to enhance the precision of cost estimation. The outcome can be attributed to the capacity of technology to present an all-encompassing and detailed illustration of the project. The integration of cost-related information into the 3D model serves to guarantee that cost projections align with the physical characteristics of the project (Khosakitchalert,

Yabuki, & Fukuda, 2020; Fadeyi, 2017). The integration results in cost estimates that are more reliable and precise.

As previously mentioned, the adoption of 5D BIM allows for continuous monitoring of project costs, as it provides real-time cost tracking and control capabilities. This enhanced cost control and monitoring feature benefits stakeholders involved in the project. Proactive cost control measures can be conducted by comparing real costs to estimates and detecting price variations (Vigneault et al., 2019). This helps keep cost overruns minimal and improves financial performance. The utilisation of 5D BIM also enables the evaluation of the financial impact of change orders through the automated recalculation of expenses linked to altered elements within the 3D model (Khosakitchalert, Yabuki, & Fukuda, 202; Babatunde et al., 2019). This simplifies the change order management procedure and aids in determining the financial effect of the suggested changes. In addition, 5D BIM allows enhanced communication and collaboration among various project stakeholders, such as owners, architects, engineers, contractors, and cost estimators. The utilisation of a 3D model to visually convey costs can improve comprehension and transparency of cost-related

data (Musonda, 2019). This can lead to more effective decision-making and communication. In brief, the incorporation of cost-related information into the digital model is a key feature of 5D Building Information Modelling (BIM). It enables comprehensive cost estimation, tracking, and control throughout the project lifecycle. 5D BIM is a powerful tool for managing costs in construction projects.

2.3. Challenges Associated with Implementing 5D BIM in Cost Management

Despite the advantages of 5D BIM for cost management in construction projects, its implementation is challenging. The successful utilisation of 5D Building Information Modeling (BIM) for cost management requires a skilled and competent team of professionals. According to Lu, Lai, & Tse (2018), the critical skills required for managing cost using 5D BIM include BIM competency, understanding of cost management principles, proficiency in 5D BIM tools, and interpreting 5D BIM output (Gohil et al., 2022; Saka & Chan, 2019; Babatunde et al., 2018).

2.3.1. Data Integration and Interoperability

Integrating cost data with the 3D model requires effective data management and interoperability between software applications. Ensuring seamless data exchange and compatibility between software platforms can be challenging, as it requires standardised data formats and protocols (Gohil et al., 2022; Yao, Qin, & Wang, 2020).

2.3.2. Resource and Skill Requirements

Implementing 5D BIM in cost management demands adequate resources, including hardware, software, and skilled personnel. Acquiring the necessary resources and training the team members in 5D BIM tools and methodologies can pose challenges, particularly for smaller organisations or those with limited budgets (Franco et al., 2015; Smith, 2014).

2.3.3. Change Management

Introducing 5D BIM into established workflows and processes may require significant changes in project teams' practices and mindsets. Resistance to change and the need for training and reorientation can be challenges that need to be addressed to ensure successful implementation (Franco et al., 2015).

2.4. Role of Professionals in 5D BIM and Cost Management

Professionals play an important part in employing 5D BIM for cost control. They require

knowledge of BIM software, cost estimation skills, and ongoing training in 5D BIM and cost management practises (Smith, 2016). The successful implementation of Building Information Modelling (BIM) practise for cost management purposes necessitates a strategic approach that can guarantee its effectiveness. These strategies include interdisciplinary collaboration, well-defined roles and responsibilities, and a culture of training and knowledge sharing (Doan et al., 2020; Babatunde et al., 2019; Charef, Alaka, & Emmitt, 2018; Smith, 2016). This section briefly discusses on these aspects.

2.4.1. Skills Required for Managing Cost using 5D BIM

Proficiency in BIM Software:
Professionals using 5D BIM for cost management should have a strong command of BIM software applications specifically designed for cost integration, estimation, and tracking (Saka & Chan, 2019). They should be adept at navigating the software's features and functionalities to extract accurate quantities, assign costs, and generate cost reports.

Cost Estimation and Analysis Skills:

Proficiency in cost estimation techniques and analysis is essential for professionals working with 5D BIM. They should possess a deep understanding of construction costs, cost breakdown structures, and cost factors relevant to the project (Ibrahim & Ghafar, 2022). This expertise enables them to make informed decisions, validate cost estimates, and perform cost-related analyses using the integrated data in the BIM model.

2.4.2. Training and Education Needed for Professionals

Training and education play a critical role in enhancing these skills, necessitating the inclusion of 5D BIM and cost management courses in academic and professional training programs (Ibrahim & Ghafar, 2022).

BIM Training Programs: Professionals should undergo specialised training programs focused on 5D BIM and its application in cost management. These programs provide a comprehensive understanding of the principles, processes, and tools related to 5D BIM (Mustafa et al., 2020). They cover cost integration, quantity takeoff techniques, cost estimation methodologies, and cost tracking and control using BIM software.

Continuous Professional Development: Given the rapid evolution of BIM technology,

professionals should engage in continuous professional development to stay up-to-date with the latest advancements in 5D BIM and cost management practices (Latiffi & Brahim, 2014). These programs can involve attending workshops, seminars, and industry conferences and participating in online courses and webinars that offer insights into emerging trends and best practices.

2.4.3. Team-Building Strategies for Successful Implementation

Interdisciplinary Collaboration:

The effective utilisation of 5D BIM for cost management necessitates collaboration and coordination among all project stakeholders, such as architects, engineers, quantity surveyors, estimators, and project managers. The seamless integration of cost-related information into the BIM model may be ensured and accurate cost estimation and tracking can be facilitated by establishing clear communication lines and cultivating a collaborative environment (Ibrahim & Ghafar, 2022).

Roles and Responsibilities:

It is important for a team to have clearly defined roles in order to maintain responsibility and clarity in the workflow of the team and to support efficient decision-making processes (Saka & Chan, 2019). This includes identifying the key personnel responsible for cost estimation, tracking, model updates, and data integration.

Training and Knowledge Sharing:

Promoting a culture of continuous learning and knowledge sharing within the team enhances the utilisation of 5D BIM for cost management. Encouraging professionals to share their expertise, experiences, and best practices facilitates skill development and improves the overall proficiency of the team (Mustafa et al., 2020). This can be achieved through regular training sessions, internal workshops, and the establishment of knowledge-sharing platforms.

2.5. Best Practices for Implementing 5D BIM in Cost Management

In order to optimise the implementation of 5D BIM in cost management and maximise its benefits, professionals should adhere to best practises. These practises include early integration of cost professionals, standardisation of workflows, utilisation of collaborative platforms, and promotion of continuous training and knowledge sharing (Doan et al., 2020; Charef, Alaka, & Emmitt, 2018). This section briefly discusses on the best practices for implementing

5D BIM in cost management as found in the literature.

Early Involvement of Cost Professionals

The involvement of cost professionals from the early stages of a project facilitates effective cost management using 5D BIM (Gohil et al., 2022). Collaboration between cost estimators, quantity surveyors, and the design team is critical for ensuring that accurate cost-related information is integrated into the Building Information Modelling model from the initial stages of a project. This collaboration is a key factor in the successful implementation of 5D BIM for cost modeling. Li, Shi, & Si (2021) support the assertion that collaboration among project stakeholders is critical for successful 5D BIM implementation. The early stages of a project are crucial for 5D BIM implementation because designers must create suitable 3D models that construction teams can check for clashes or discrepancies. Moreover, 5D BIM can help quantity surveyors during the early stages of a project by reviewing alternative designs and making informed decisions using approximated quantities extracted from other different 3D BIM models (Franco, Mahdi, & Abaza, 2015).

Standardisation of Cost Data and Workflows

A standardised cost databases, workflows, and templates streamlines cost data helps the integration process for the 3D model (Smith, 2016). A well-defined and clear workflow with protocols for cost estimation, change order management, and cost tracking helps ensuring consistency and improves efficiency in implementing 5D BIM for cost management.

Collaboration and Communication Platforms

The establishment of collaborative BIM platforms or cloud-based solutions enable seamless information sharing and coordination among project stakeholders. These platforms facilitate real-time collaboration, document management, and communication, enhancing the efficiency and effectiveness of cost management activities (Musa et al., 2018; Charef, Alaka, & Emmitt, 2018). In the past, cost estimators and quantity surveyors had to review revised documentation manually to identify changes made by architects and designers. However, with 5D BIM, there is a significant reduction in the time and effort required for this process. Additionally, 5D BIM allows for real-time online meetings between stakeholders to discuss changes in the design and cost (Musonda, 2019).

Continuous Training and Knowledge Sharing

The adoption and implementation of 5D BIM in construction projects require a highly skilled and knowledgeable project team, making continuous training and professional development opportunities crucial in ensuring successful project delivery (Musonda, 2019; Mustafa et al., 2019). This can be achieved by providing consistent training and professional development opportunities to enhance the team's proficiency in 5D BIM and cost management. Cultures such as fostering knowledge sharing among team members through frequent meetings, workshops, and sessions dedicated to reviewing lessons learned cultivates a process of ongoing education and enhances the overall proficiency of the team.

2.6. Future of 5D BIM in Cost Management

The future of 5D Building Information Modelling (BIM) in cost management is a topic of great interest, as it is expected to bring about significant advancements in the construction sector. This is due to the emergence of new trends and advancements in technology. The following section explores potential future developments and benefits that are associated with these advancements.

2.6.1. Emerging Trends in 5D BIM and Cost Management

Integration with Artificial Intelligence (AI)

The integration of AI technologies with 5D BIM has the potential to revolutionise cost management (Lu, Lai, & Tse, 2018). AI algorithms can analyse historical cost data, predict cost trends, and provide real-time cost insights, enabling more accurate cost estimation, risk assessment, and decision-making.

Cloud-based Collaboration and Data Management

Cloud-based collaboration platforms facilitate gives real-time access to the 5D BIM model and cost-related information, regardless of geographical location (Ibrahim & Ghafar, 2022). This enables seamless collaboration, data sharing, and synchronisation among project stakeholders, improving efficiency and reducing communication barriers.

Mobile and On-site Applications

Mobile applications and on-site tools for 5D BIM provide field personnel with immediate access to cost-related information, allowing them to update cost data, track progress, and capture on-site data in real time (Ibrahim & Ghafar, 2022). This streamlines the cost management process and

enhances the accuracy and timeliness of cost-related decisions.

2.6.2. Technological Advancements Impacting 5D BIM and Cost Management

Internet of Things (IoT)

The Internet of Things (IoT) refers to the interconnectivity of physical devices and objects via the internet, allowing them to share data and communicate with each other. The integration of IoT devices and sensors with 5D BIM can enhance cost management by capturing real-time data on resource usage, energy consumption, and equipment performance (Pezeshki & Ivari, 2016). The data can be used for cost optimisation, predictive maintenance, and energy efficiency analysis.

Big Data Analytics

Big data analytics is the process of examining large and complex datasets to identify patterns, trends, correlations, and other useful insights. The field of big data analytics involves using advanced computational and statistical techniques to analyze vast amounts of digital information with the aim of extracting valuable knowledge that can be used for decision-making (Lu, Lai, & Tse, 2018). With the increasing availability of data

from various sources, big data analytics can be leveraged to extract valuable insights for cost management (Shafei et al., 2022). By analysing large volumes of cost data, patterns, trends, and cost drivers can be identified, enabling more accurate cost estimation, risk assessment, and cost control strategies.

3. CONCLUSION AND RECOMMENDATION FOR FUTURE RESEARCH

To summarise, the implementation of 5D Building Information Modelling (BIM) can provide valuable advantages in terms of cost management as it allows for the seamless integration of cost-related data into the digital model. This paper emphasises the significance of 5D BIM in enhancing cost estimation accuracy, cost tracking and control, change order management, and promoting collaboration and communication among project stakeholders. The implementation of 5D BIM in cost management can present some challenges, including the need for effective data integration and interoperability, adequate resources and skills, and careful change management.

It is important to consider implementing best practises to effectively address the challenges at hand. This involves effective collaboration of

cost professionals, standardising workflows, utilising collaborative platforms, and promoting continuous training and knowledge sharing.

It is also important to acknowledge that there are many exciting possibilities for the future of 5D BIM in cost management. It is worth noting that the integration of AI, cloud-based collaboration, and mobile applications are some of the emerging trends that are expected to enhance the capabilities of 5D BIM. The emergence of IoT and big data analytics presents exciting prospects for enhancing cost management processes and gaining insightful knowledge. Other than that, these are recommendations of possible areas for future exploration in the field of 5D BIM and cost management.

Advanced Artificial Intelligence (AI) Integration

It may be beneficial to explore the potential of advanced AI algorithms that incorporate machine learning and predictive analytics to improve accuracy in cost estimation, risk assessment, and decision-making within cost management.

Sustainability Integration

Investigating the integration of sustainability-related data into 5D BIM models can provide insights into the life cycle costs and environmental impacts of construction projects,

enabling more sustainable cost management practices.

Advanced Visualisation Techniques

Research can explore the use of augmented reality (AR) and virtual reality (VR) technologies to enhance visualisation and decision-making in cost management, allowing stakeholders to experience and interact with cost-related information in immersive environments. Through the advancement of research in these directions, the construction industry can fully unlock the capabilities of 5D BIM in the area of cost management, resulting to more accurate cost estimations, efficient cost control, and improved project outcomes.

In conclusion, this review paper has consolidated and synthesizes existing research on the role of 5D Building Information Modelling (BIM) in construction project cost management as its contribution to the existing body of knowledge. This review has provided insights and practical implications for the construction industry professionals and stakeholders involved in project cost management. This study also believed that the effective utilisation of 5D BIM in construction project cost management can have broader societal benefits. The benefits of 5D BIM, in turn, can help minimise cost overruns, reduce project

delays, and improve overall project outcomes. Consequently, the adoption of 5D BIM can lead to more sustainable construction practices, as it allows for better resource management and waste reduction, ultimately contributing to environmental sustainability for the current and future generations.

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