Journal of Information System and Technology Management
JISTM
EISSN: 0128-1666
Volume 11 Issue 43 (June 2026) PP 64-84


**JOURNAL OF INFORMATION SYSTEM AND TECHNOLOGY MANAGEMENT (JISTM)**
www.gaexcellence.com/jistm

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# A CONCEPTUAL INTEGRATION OF 5D BIM AND BIG DATA ANALYTICS FOR ENHANCED PROJECT COST MANAGEMENT

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**Article Info:**

**Article history:**
Received date: 15.02.2026
Revised date: 16.03.2026
Accepted date: 14.04.2026
Published date: 10.06.2026

To cite this document:

Ali, F. H., & Habib, S. N. H. A. (2026). A Conceptual Integration Of 5D BIM and Big Data Analytics for Enhanced Project Cost Management. *Journal of Information System and Technology Management, 11* (43), 64-84.

**DOI:** 10.35631/JISTM.1143004

**Abstract:**

Project cost management (PCM) is crucial for achieving cost efficiency and financial control in construction projects. However, persistent issues remain such as the reliance on outdated and incomplete historical data, which often leads to inaccurate cost estimation and forecasting. While 5D Building Information Modelling (BIM) offers improvement in cost data integration, it struggles when managing large and complex datasets. Big data analytics (BDA) has therefore been proposed as a complementary approach to enhance BIM capabilities by enabling advanced data processing and predictive analytics. However, the conceptual relationships between 5D BIM, BDA and PCM remain insufficiently explored in existing literature. This gap highlights the need for a better understanding of their integration. Therefore, the present study reviews and synthesizes existing literature on 5D BIM, BDA and PCM to develop a theoretical framework that highlights the key components and potential benefits of their integration. The findings provide a foundation for future empirical research and support decision-makers in evaluating the strategic value of investing in BDA to enhance BIM-enabled project cost management.

**Keywords:**

Big Data Analytics, Project Cost Management, Solution, 5D Building Information Modelling

Journal of Information System and Technology Management
JISTM
EISSN: 0128-1666
Volume 11 Issue 43 (June 2026) PP 64-84



## Introduction

Project cost management (PCM) is one of the imperative aspects of construction project where it forms the core of project management with quality and time management (George; & Vallance, 1987; Memon et al., 2010; Unegbu et al., 2023). The importance of PCM can be further depicted as the Project Management Institute (PMI) includes it among the ten project management knowledge areas as the fundamental (Peter, 2023). PCM encompasses planning, estimation, budgeting, financing, controlling and managing costs, to ensure that the project can be accomplished within the agreed budget (Lewis, 2016). Based on this definition, the main processes include plan cost management, estimate costs, determine budget and control costs (Lewis, 2016; Memon et al., 2010; Unegbu et al., 2023).

Commonly, conventional PCM approaches involve the use of spreadsheets, manual data entry, and periodic reporting to monitor expenses, track budget allocations, and identify potential cost overruns (Bettemir & Yücel, 2023; Ciotta et al., 2021). However, these methods often tangled with various issues such as the use of obsolete data, difficulties in integrating data from multiple sources, and the potential for errors due to manual data inputs (Kern & Formoso, 2004; Lu et al., 2018; Parsamehr et al., 2023). As construction projects become more complex, the need to enhance PCM practices while improving its data management becomes increasingly demanding, thus leading to the need for technological advancement (Parsamehr et al., 2023). Therefore, digitalizing PCM is considered a step towards addressing projects' data management issues.

## Literature Review

Digitalization is achieved by leveraging digital technologies and digitizing data to transform the working method and produce new revenue (Bloomberg, 2018; Wade, 2018). Despite the construction sector being identified as one of the least digitized sectors in 2015, McKinsey reported substantial growth within the sector from 2020 to 2022 (Jose et al., 2023). Among various reasons for the construction digitization, policy implementation plays a crucial role, hundreds of national digitalization policies introduced between 2017 and 2022 (Jingxiao et al., 2023). In the Malaysian construction sector, Construction Industry Development Board (CIDB) has published Construction 4.0 Strategic Plan (2021-2025) to support the 4$^{th}$ Industrial revolution through emerging technologies (CIDB, 2020) as in Figure 1.

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EISSN: 0128-1666
Volume 11 Issue 43 (June 2026) PP 64-84

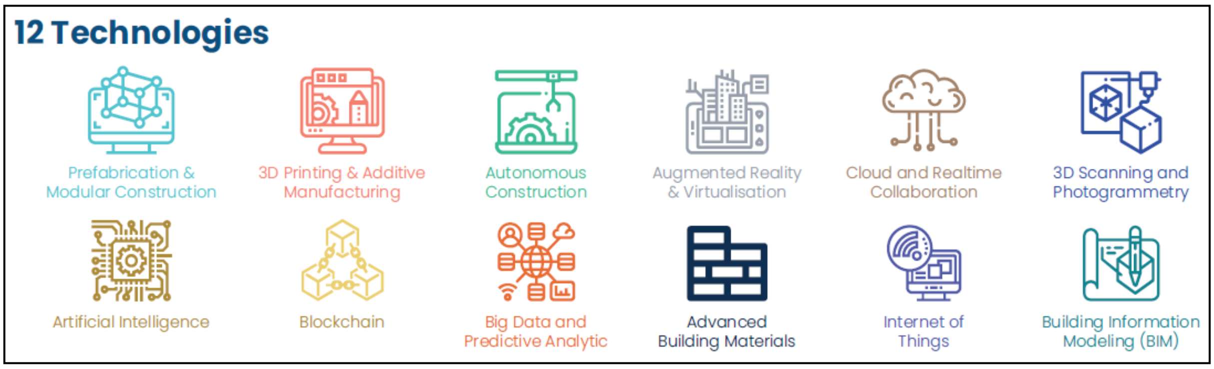


**Figure 1: Emerging Technologies in Construction Sector**

Source: (CIDB, 2020)

Among the emerging technologies, BIM is viewed as a modern working method to address data management issues in line with the needs of digital age (Kaufmann et al., 2018; Moreno et al., 2019; Smith, 2016). According to CIDB (2024), BIM is a process of preparing, utilizing and sharing 3D models through a digital platform that encompasses multiple types of information that can be accessed and leveraged by all project stakeholders to achieve the project objectives throughout the execution. In the context of PCM, 5D BIM has diverse functions such as estimation, quantification, collaboration and intelligent revision, which reflect the management of design, material, cost and schedule data through its platform (Charef et al., 2019; Jiang & He, 2020; Latiffi et al., 2017; Moreno et al., 2019). Therefore, embracing 5D BIM can improve accuracy and facilitate better decision-making throughout the project lifecycle (Farouk & Rahman, 2023). However, BIM becomes limited when projects become more complex and involve large datasets. For example, an infrastructure project can reach up to 2.3TB, while three-storey building model can be around 50 GB within common data environment (Azman, 2018; Bilal et al., 2016). Therefore, the adoption of BDA is considered as potential resolution to address the data management issues in PCM while supplementing 5D BIM (Chen, 2022). BDA refers to the systematic processing of voluminous and complex data to extract invaluable insights (Mucci & Stryker, 2024). Although the concept of big data has been emphasized since the early of 21$^{st}$ century, the effort to adopt it in the construction sector has only gained traction recently (Maaz et al., 2018; Press, 2013). In contrast, other sectors such as manufacturing, financial institutions, and hospitality have already leveraged big data technologies to improve productivity and support data-driven decision (Kumar et al., 2018; Niesen et al., 2016; Rabhi et al., 2019). In 2023, Klynveld Peat Marwick Goerdeler (KPMG) reported that advanced data analytics and BIM are among top technologies with high potential for return of investment (ROI) (Armstrong et al., 2023). Hence, integrating these technologies enhance performance within the sector, particularly in PCM. Several studies demonstrate how the interaction between BDA and BIM, as shown in Table 1.

**Table 1: Existing Studies on BDA and BIM**

| Construction sub-domains | Potential opportunities | Authors |
|---|---|---|
| **Safety management** | -Management of construction sites to avoid unsafe behaviours of workers (smart safety).<br>-Usage of BIM for construction safety management. | Fang et al. (2024), Koc et al. (2023),Parsamehr et al. (2023) |

| | | |
|---|---|---|
| Cost management | -BIM and big data for construction cost management. | Lu et al. (2018), Huang (2021a) & Smith (2016) |
| Waste management | -Construction waste analytics using big data. | Bilal; et al. (2016) |
| Smart Construction | -Leveraging AI, IoT and big data for smart and sustainable architecture. | Rane (2023), Yin (2023) & Bibri et al. (2023) |
| Facility management | -BDA and BIM for operation and maintenance activities | Arslan et al. (2017); Aziz (2017); Demirdogen et al. (2023) |
| Energy management | -BDA for simulation and optimization of energy leveraging BIM software. | Shen and Pan (2023); Wang et al. (2022) & Xiao and Fan (2022) |

Despite the existing studies, there are little to no studies made focusing on PCM conducted on BIM, Big Data and Project Management. This is illustrated in the overlay visualization as shown in Figure 2.

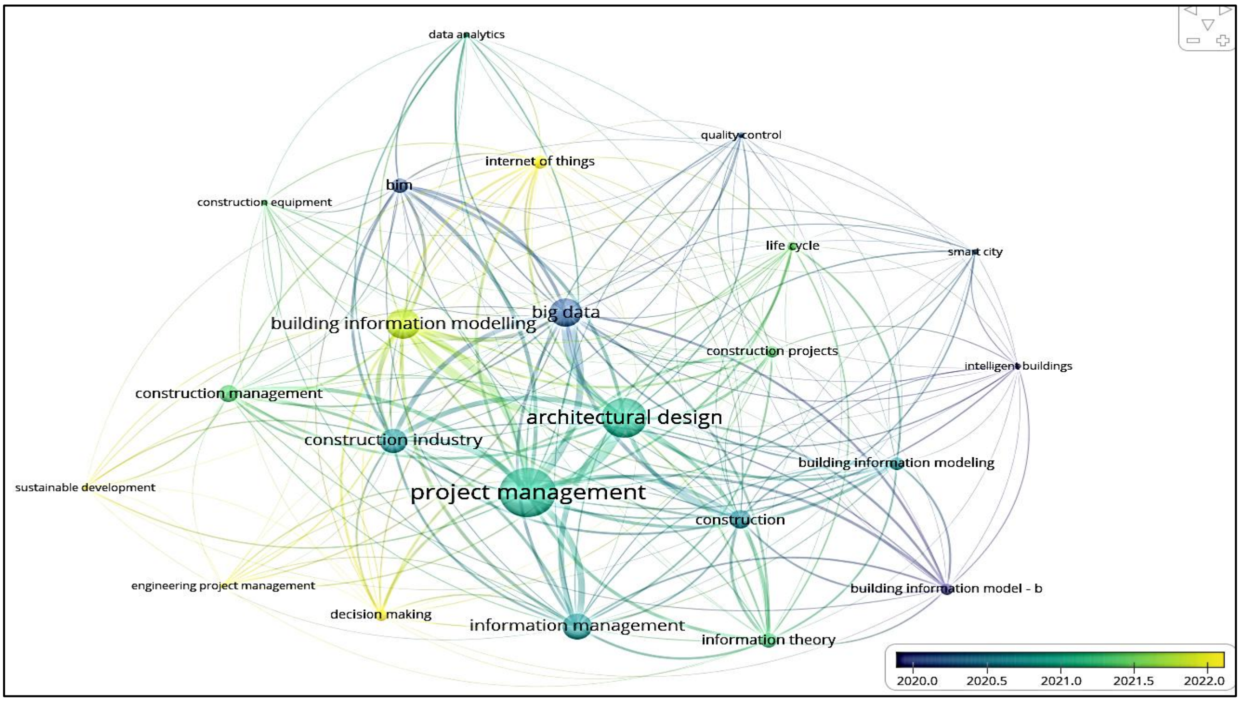


**Figure 2: Overlay Visualization on BIM and Big Data**

As 5D BIM software and BDA are considered spearheads in improving PCM's existing issues, several potential functions have been identified (Lu et al., 2018; Opoku et al., 2021). One of the plausible functions is the use of various project documents to extract insights such as rare cost and quantity information for specialized trades or elements, which can be utilized within BIM platform for quantification purposes (Collab, 2023; Huang, 2021b; Lu et al., 2018). Additionally, BDA has the capability to support early identification and assessment of risks, and the insights can be brought into the BIM model for project monitoring (Lynch, 2018; Obaid & Abu-Naser, 2023). Furthermore, patterns of resources and prediction of resource requirements are viable through the BDA platform; this information can help to improve resource optimization within BIM platform (Farghaly, 2019; Obaid & Abu-Naser, 2023).

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EISSN: 0128-1666
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Thus, with the transition from conventional to more integrated and data-drive approaches, construction firms can effectively navigate challenges, mitigate risks, and achieve greater efficiency and transparency in managing project costs (Shojaei et al., 2023). These integrated capacities highlight the need for further research on combining both domains to address the challenges of conventional PCM and its data management. Therefore, the present study develops a theoretical framework of integrating 5D BIM and BDA for project cost management, which aims to support justifying the investment in procuring these technologies.

## Methodology

Fundamentally, this research is exploratory in nature as there is no known studies that have explored this area in depth (George, 2023). Before the deeper exploration of this research area, leveraging existing data from various sources to develop the theoretical framework (Ajayi, 2017; Manoharan, 2009). However, in order to ensure the reliability of the data obtained, the following research methodology framework was developed (see Figure 3).

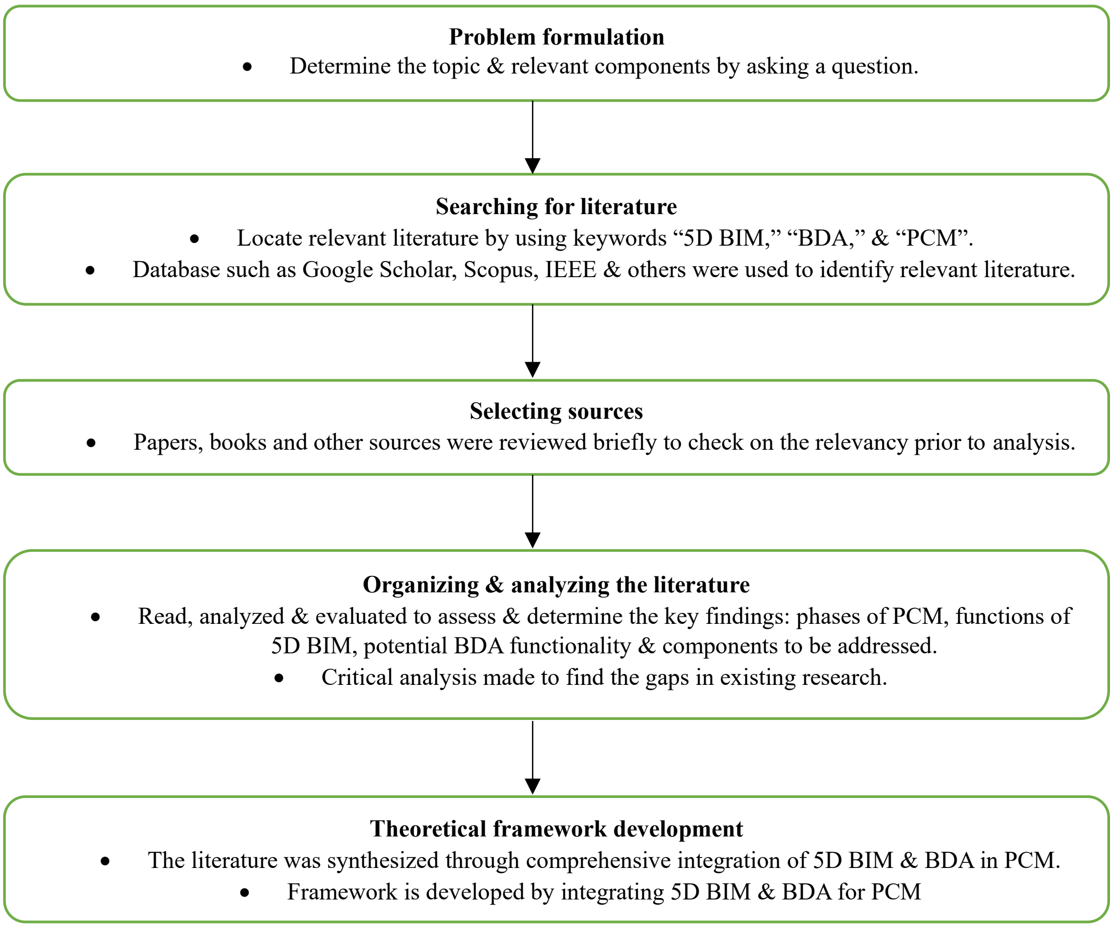


**Figure 3: Research Methodology Framework**

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EISSN: 0128-1666
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## Research Findings and Discussion

### *Phases of Project Cost Management*

#### *Cost Planning*

According to RICS (2009), a cost plan is defined as a breakdown of the project's cost limit into targeted allocations of each construction element. This elemental cost plan is commonly divided into substructure, superstructure, finishes, fittings and furnishings, services and external works. The purpose of the cost plan is to establish the cost parameters throughout design development stages, thus ensuring the project is within the client's proposed budget. A cost plan also serves as the foundation for the subsequent detailed cost estimation and budgeting activities. (Scott, 2015; Westland, 2007).

During the cost planning process, the project team, including the client, project manager, QS, and other consultants engage in a meticulous analysis of historical cost information derived from previous similar nature of construction projects. This process takes into consideration factors like price fluctuation, contingency, contractors and laborers' hourly rates and risks (Antidormi, 2023b; Ayodele & Kajimo-Shakantu, 2022). Once the required data is gathered, the cost plan will be developed, providing a structured foundation for subsequent budgetary considerations (Sharma et al., 2013). Additionally, cost planning involves active engagement with key stakeholders to define and establish cost constraints and expectations. The collaborative nature of this engagement is important in aligning financial parameters with project goals and stakeholder expectations (Cerezo Narvaez et al., 2020; Venkataraman & Pinto, 2023).

Furthermore, the significance of cost planning extends beyond financial forecasting, encompassing a strategic alignment with project objectives. The integration of cost planning into the early phases of project management promotes a proactive approach in identifying potential challenges and opportunities (Anderson et al., 2007). This enables the project team to address constraints effectively, optimize resource utilization, and foster a cohesive understanding among stakeholders regarding the financial parameters governing the project (Venkataraman & Pinto, 2023). Hence, the outcome of the cost plan is to aid the creation of the project budget as well as the resource plan (Antidormi, 2023b). In essence, cost planning not only charts a financial roadmap for the project but also contributes to enhance decision-making and successful project outcomes.

#### *Cost Estimation*

Cost estimation is a pivotal method within project cost management that involves the systematic prediction of probable project costs based on available information and comprehensive analysis (Radzi et al., 2023; Ramabodu, 2014). This component is particularly useful during the early stages of a project, where it acts as a benchmark by providing an overview of the cost throughout various stages of construction (Antidormi, 2023b). During the preparation phase, project managers and quantity surveyors (QS) often work with limited data on the feasibility, where the information includes land acquisition costs, the construction costs, operation and maintenance costs (Hendrickson et al., 2024; Lu et al., 2018). Since this estimation heavily relies on assumptions and predictions, data such as recorded cost information and data from projects with similar attributes are utilized to generate preliminary

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estimates, which are less accurate and subject to change as more information becomes available (Antidormi, 2023b; Lu et al., 2018).

In the design stage, information becomes much richer, and a more detailed estimate can be performed (Dana & Tardif, 2009). As designs are provided by designers, a comparative estimate can be carried out by QS to give a few options to the client in terms of the alternative designs and materials options (Lu et al., 2018). If these alternatives are not considered during this stage, it may significantly impact the overall project in the latter stages, as depicted in Figure 4 (PMI, 2013).

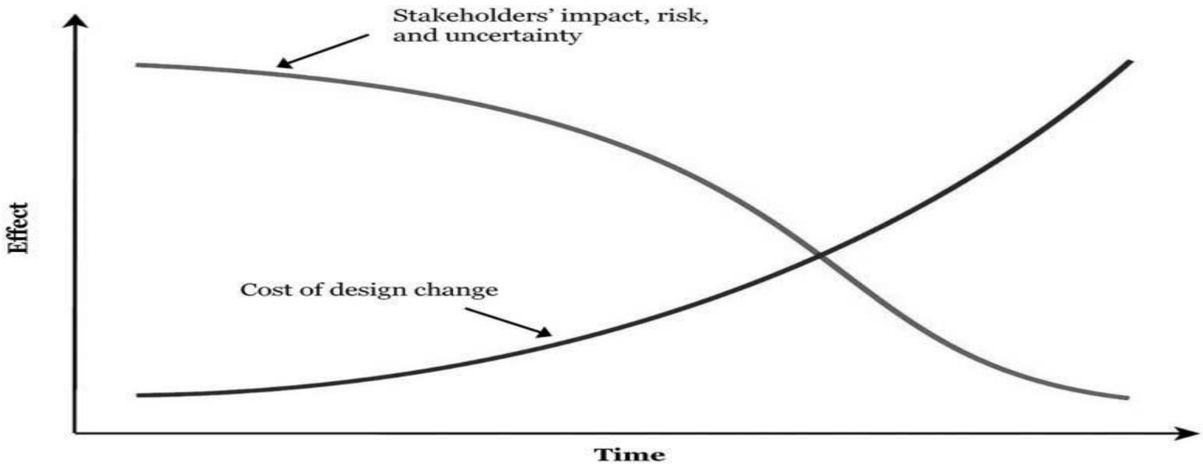


**Figure 4: Impact of Changes Throughout Project Timeline**
Source: (PMI, 2013)

Then, during the tendering stage, completed drawings are provided by design consultants, allowing the QS to perform pre-tender estimates and tender documents before the call for tender (CIOB, 2018). One of the main outputs in this process is the Bills of Quantities (BoQ), which is commonly prepared based on the Standard Method of Measurement (SMM), comprises materials quantities, labour works, contingencies and other relevant items involved in the construction projects (Hendrickson et al., 2024; Lu et al., 2018). Therefore, it can be concluded that all these estimation requires various data information throughout the project period, which includes resource requirements, pricing and duration required for each resource, assumptions, potential risks and project benchmarks (EcoSys, 2023).

***Budgeting***

Budgeting is another critical component of PCM in which cost estimation and cost planning act as the foundation for this process. As articulated by Musarat, Alaloul, and Liew (2021), this stage is characterized by a meticulous alignment of cost estimates with the project timeline, thus establishing a strategic framework for cost distribution. A construction budget can be defined as the estimated amount of all costs required for the completion of a construction project from the initial to the completion phase (Antidormi, 2021). Although the construction cost is a substantial fraction of the overall project cost, other costs also contribute to budget development (Hendrickson et al., 2024). The project budget is considered complete when all construction costs and contingency reserves are added to the management reserve, as shown in Figure 5 (Iqbal, 2019).

The contingency reserve is allocated to absorb the financial impact due to the uncertainties and risks related to the construction projects, where estimation techniques such as Expected Monetary Value (EMV) are used to estimate its value (Bakhshi & Touran, 2014; Iqbal, 2019). On the other hand, management reserves concerns about unplanned changes, where estimating it is quite complicated due to inherent risks that are unpredictable, thus conventional percentage technique is used for this purpose (Pyo et al., 2017). Both contingency and management reserves are maintained to accomodate voluntary and mandatory changes required by the client or contractor throughout the construction stage (Kimmons & Loweree, 2017). Despite the allocation of reserve funds, the responsibility and authority for both funds lie with different persons, where the project manager manages the contingency reserve, while the management reserve fund is controlled by the senior management (Iqbal, 2019).

In conclusion, budgeting is not merely a procedural step but a strategic initiative that contributes to the overall financial management of a project (Buck et al., 2024). The crucial relationship among cost allocation, control mechanisms, and contingencies highlights its essential role in maintaining financial viability and ensuring the success of the project.

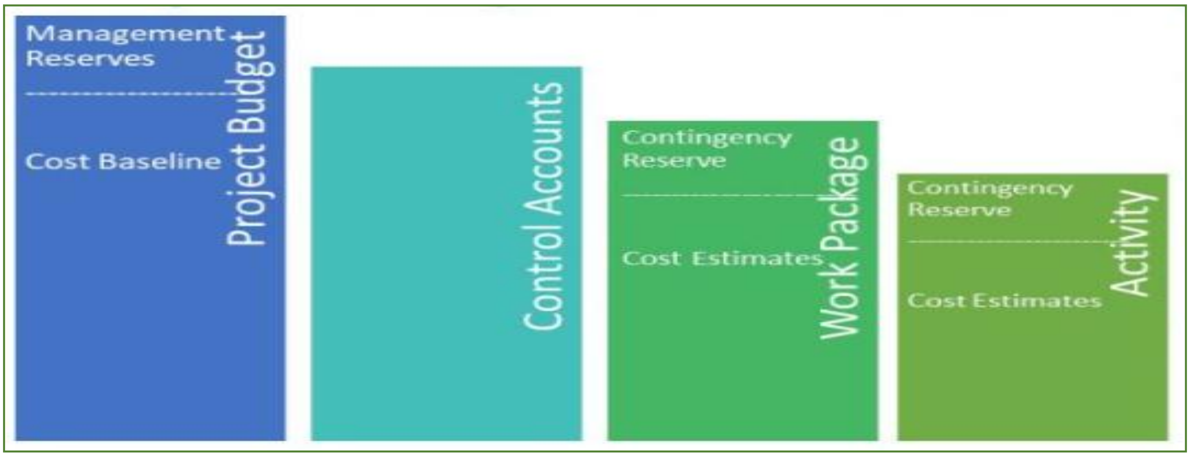


**Figure 5: Components of Project Budget**

Source: (Iqbal, 2019)

### *Cost Control*

During the construction phase, cost control becomes the focal point of QS (Lu et al., 2018). Cost control is another essential component of PCM, where it is an ongoing process dedicated to monitoring and managing project costs to ensure alignment with the approved budget, while allowing adjustments to the cost baseline if required (PMI, 2013; Venkataraman & Pinto, 2023). This process involves continuous monitoring of financial expenditures and the implementation of corrective actions when necessary to prevent cost overruns, projects delays, resource shortages, and other issues (Antidormi, 2023a; Del Pico, 2023).

The effectiveness of cost control relies on key activities that form the foundation of a proactive cost management strategy. One of these activities is regular cost tracking, where project managers and QS maintain a real-time understanding of cost dynamics, allowing them to identify trends, potential risks, and areas requiring intervention (Ahmed et al., 2023). Furthermore, the investigation of cost overruns is a crucial aspect of cost control, allowing project teams to scrutinize into the root causes of deviations and implement corrective measures promptly (Catalão et al., 2023; Oyegoke et al., 2022). Hence, the primary objective of cost

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control is to prevent deviations from the approved budget while ensuring that appropriate actions are taken when variations occur (PMI, 2013). If the necessary actions are not taken, the actual cost may go beyond the baseline planned earlier, as shown in Figure 6 (Lu et al., 2018). In Figure 6, although the actual cost exceeds the cost baseline, the cumulative value can still remain within the project budget through the utilization of management reserve (Usmani, 2024). If cost control is not effectively implemented and necessary actions are not taken, most probably the project will be overbudgeted and cause project failure.

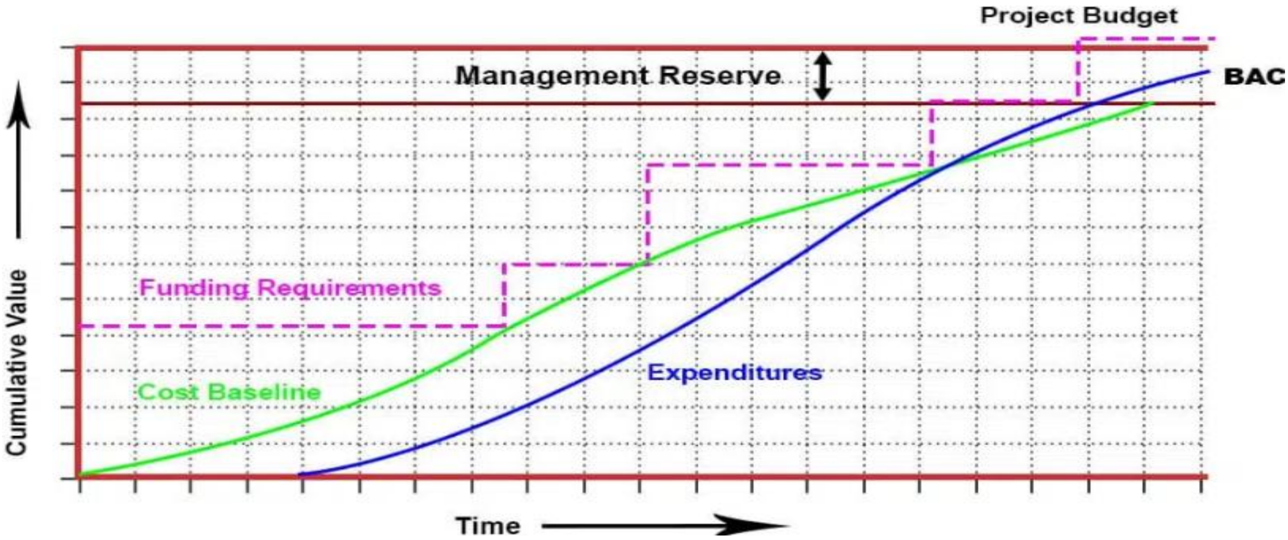

**Figure 6: Cost Baseline against Actual Cost**

Source: (Usmani, 2024)

In summary, PCM components are interconnected, where cost planning provides the foundation for detailed cost estimation, which, in turn, informs the creation of the project budget. The budget becomes a dynamic reference point for cost control, guiding ongoing monitoring and management efforts to ensure adherence to approved financial parameters. This interconnected approach ensures financial transparency, effective resource utilization and proactive responses to deviations, which contribute to the overall success of the project. Despite its well-established practices, conventional project cost management is facing limitations and challenges in responding quickly to evolving project dynamics (Tariq & Gardezi, 2023).

***Functions of 5D BIM***

***Accelerated Quantity Take-off***

Automated and rapid quantification represents a shift from the conventional practices in the field of construction and cost estimation, where it harnesses the power of technology to expedite the common time-consuming process of measuring and quantifying materials (Fahmilia & Isvara, 2023). This modern approach enhances the efficiency and accuracy of quantity estimates, offering a marked improvement over the manual method (Sing et al., 2022). This directly reflects that this automation process not only accelerates the speed at which estimates are generated but also minimizes the likelihood of errors, ensuring a more reliable foundation for project planning and decision-making (Al-Musawi & Naimi, 2023).

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Besides, by leveraging this capacity, the collaboration between project stakeholders can be enhanced since the outputs from the 5D model provide standardized and clear documentation that can be easily understood across various different teams (Gaur & Tawalare, 2022). Furthermore, as projects become increasingly complex and timelines become more stringent, the adoption of advanced technologies becomes increasingly imperative for maintaining competitiveness (Rane, 2023). The use of accelerated quantity take-off methods enables QSs to manage the complexity of estimating material quantities more effectively, ultimately contributing to improved project outcomes.

#### *Automated Bills of Quantities (BOQ)*

In addition to automated quantity take-off, an automated Bill of Quantities (BOQ) can also be generated via 5D BIM software, where it connects cost data with the details from the 3D and 4D models (Rajapaksha et al., 2023). This shift from conventional to modern approaches illustrates not only improved speed in BOQ production, but also reflects the dynamic ability to adopt to changes across multiple models from different stakeholders (Smith, 2016). For example, when there is a modification in cost data, the software can capture the changes in real-time and automatically update the BOQ (Li & Kassem, 2021). This adaptability ensures that information within the 5D model is accurate and up to date.

#### *Intelligent Revision Management*

5D BIM also stands out as a crucial asset by providing intelligent revision management within BIM projects, where it integrates design alterations and schedule adjustments, to automatically update the relevant cost data (Glodon, 2021). Thus, this ensures that project cost estimates remains aligned with the current progress while indirectly mitigating the risks arising from outdated information (Dan et al., 2023). Besides its capacity to capture the changes, the software used in 5D BIM can generate comprehensive reports that define the cumulative impacts of revisions on the overall project schedule and cost (Alzara et al., 2023). Thus, these reports provide a clear understanding on the overall impact or the influence these revisions to the stakeholders.

#### *Integrated Cloud Collaboration*

Cloud collaboration enables various stakeholders to work together by integrating project data that comprises design, material, schedule and cost data within a common data environment (Glodon, 2021). As this collaboration is feasible through a cloud-based system, it eliminates geographical limitations, allowing project stakeholders to share, update and access project data from any location (Smith, 2016). This capability not only enhances collaboration among key stakeholders but also accelerates the change management processes within the project environment.

### *Plausible functions of BDA*

#### *Cost Estimation*

Although 5D BIM software has improved existing project cost management, some limitations within the platform can be addressed through the adoption of BDA. It is evident that QS firms possess abundance of drawings, BOQ, tender and contract documents, and schedule of rates from various projects, which leading to the creation of big data (Lu et al., 2018; Rathnayaka et al., 2023). From this formation, insights such as rare cost, deduction and quantity information for specialized trades, finishes or elements can support quantification and high-level estimation (Lu et al., 2018).

Furthermore, some studies have proposed to integrate quantities information of the BIM model into a comprehensive big data-building information database (Huang, 2021b). Hence, this reflects the potential application for identifying historical data patterns and developing predictive models, leading towards more data-driven, automated and accessible cost estimation (Collab, 2023). However, such applications only possible through the establishment of reliable and well-structured cost database (Chen & Dai, 2021).

***Risk Identification and Mitigation***

Construction projects have always been riddled with a lot of uncertainties that may lead to disputes, cost and schedule overruns, thus requiring appropriate risk mitigation strategies (Antoniou & Tsioulpa, 2024). BDA is capable of performing early risks identification and assessment, which can reduce negative impacts on project performance through data-driven approaches (Obaid & Abu-Naser, 2023).

In the context of PCM, BDA can support tender price evaluation system by establishing price benchmark for the specific project (Lu et al., 2018). The tendering system can automatically perform calculations and alerts when the submitted tenders exceeds predefined parameters (Gorecki, 2018; Zhang et al., 2015). This enables project teams proactive steps to address the issue and avoid potential future risks such as poor quality of work, delays and budget overruns (AIA, 2023; Gorecki, 2018; Obaid & Abu-Naser, 2023). Therefore, the insights generated from BDA integrate into BIM models for project monitoring purposes (Lynch, 2018).

***Resource Optimization and Efficiency Improvement***

Project success is highly dependent on resource optimization which is achievable by ensuring all the limited resources, such as human capital, budget and time, are effectively used (Kerzner, 2017). However, construction traditionally always struggles to ensure that the resources are properly allocated (Borg & Scott-Young, 2020; Sami Ur Rehman et al., 2022). Hence, this struggle can be overcome by leveraging BDA, which has the potential to optimize resource allocation and improve construction efficiency (Obaid & Abu-Naser, 2023).

Some studies indicate that BDA can prove insights such as usage patterns of resources, prediction of resource requirements and recommendations of corrective actions (Hatefi et al., 2015; Ramasesh & Browning, 2014). The insights attained can be integrated into the dynamic BIM models development, leading towards improved project scheduling and costs (Farghaly, 2019; Marzouk & Enaba, 2019; Meredith et al., 2017). Overall, BDA can be regarded as one of the essential enablers of construction sector transformation, although it will only be able to bring improvement once the sector is ready to adopt the technology.

### *Components for Integration*

#### *People*

People play an essential role in 5D BIM implementation, where involving professionals such as architects, engineers, QSs, project managers, contractors, subcontractors, and owners, all of whom engage with integrated 3D models and associated time (4D) and cost (5D) data. For instance, QSs and project managers utilize 5D BIM to generate accurate cost estimates, track budget performance, and support decision-making process (Sing et al., 2022). Despite the existence of these professionals, the human factor is not only concerned about the technical capability and knowledge, but also their readiness to adopt the technology and adapt to change (Nicoleta, 2023). This directly reflects that this component can hinder the implementation due to the its siloed nature of the construction industry and differing perspectives on the adoption. Therefore, the people component is often prioritized over other components, in facilitating successful implementation (Trivedi, 2017).

Meanwhile, sourcing big data expertise remains challenging and costly due to the novelty of this field (Marr, 2019; Mikalef et al., 2018). Such roles require individuals equipped with a computational and analytical background, often referred to as data scientists (McAfee et al., 2012). Despite their expertise, data scientists must acquire industry knowledge through understanding industry practices they are in (Van Der Aalst, 2016). Concurrently, the big data projects, particularly in construction, should not rely solely on the data scientist, but must involve construction professionals to ensure the attainment of reliable insights.

#### *Process*

Once all the relevant components related to people are fulfilled, the next concern is the process. The process should involve well-defined workflows, from project planning to cost estimation and control, ensuring that cost data is properly integrated into the 3D models and schedules (Mustafa et al., 2023). However, construction professionals with extensive experience in the industry are often struggling in adopting and implementing BIM processes. They tend to utilize the technology most easily and shortly, often embedding it within conventional workflows, which lead to ineffective implementation (Trivedi, 2017). For instance, in current practices, it is often found that professionals using Microsoft Excel for the same project on one screen while working with BIM tools on the other (Babatunde et al., 2019). This results in repetitive tasks engagement, although workflows could be streamlined by employing Excel-to-Revit integrations to automatically create elements within Revit from Excel data (Bonduel, 2016; Trivedi, 2017). Hence, it is imperative to recognize that more efficient and effective methods are available, urging us to embrace smarter approaches.

On the other hand, big data projects are inherently innovative and necessitates specialized approaches (Gao et al., 2015). As such, big data teams must be capable to handle the analytical process appropriately, especially in providing flexible responses when there are changes. Changes are often required due to ongoing data management issues encountered during big data analysis, which compel immediate responses (Sicular, 2012). This situation reflects the importance of the data management in the big data process, in ensuring its effectiveness.

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***Technology***

After addressing the people and process aspects, technology is another imperative component to be concentrated. Software serves as the foundation of digital transformation within PCM in construction projects (Turkova et al., 2020). This requires considerable improvement to conventional IT infrastructure, which involves establishing tailored hardware and software configurations as well as clear data exchange formats, storage procedures and version management for optimal utilization of BIM models (Hamed, 2011).

However, large amount of data are generated in construction projects, which traditional database systems are often unable to handle effectively (Bilal et al., 2016). This leads to the underutilization of data, remains unnoticed and unexploited in conventional systems (Boton et al., 2015). Hence, BDA should be implemented and integrated with 5D BIM to address this issue. However, there are three key maturity areas of 5D BIM and BDA technologies, which are software, hardware and data interoperability and security, which must be addressed prior to adopting and integrating them (Bilal et al., 2016; Lily, 2023).

Considering the phases of PCM, the multifunctionality of 5D BIM, the plausible functions of BDA and the integration components, the following theoretical framework is developed as in Figure 7.

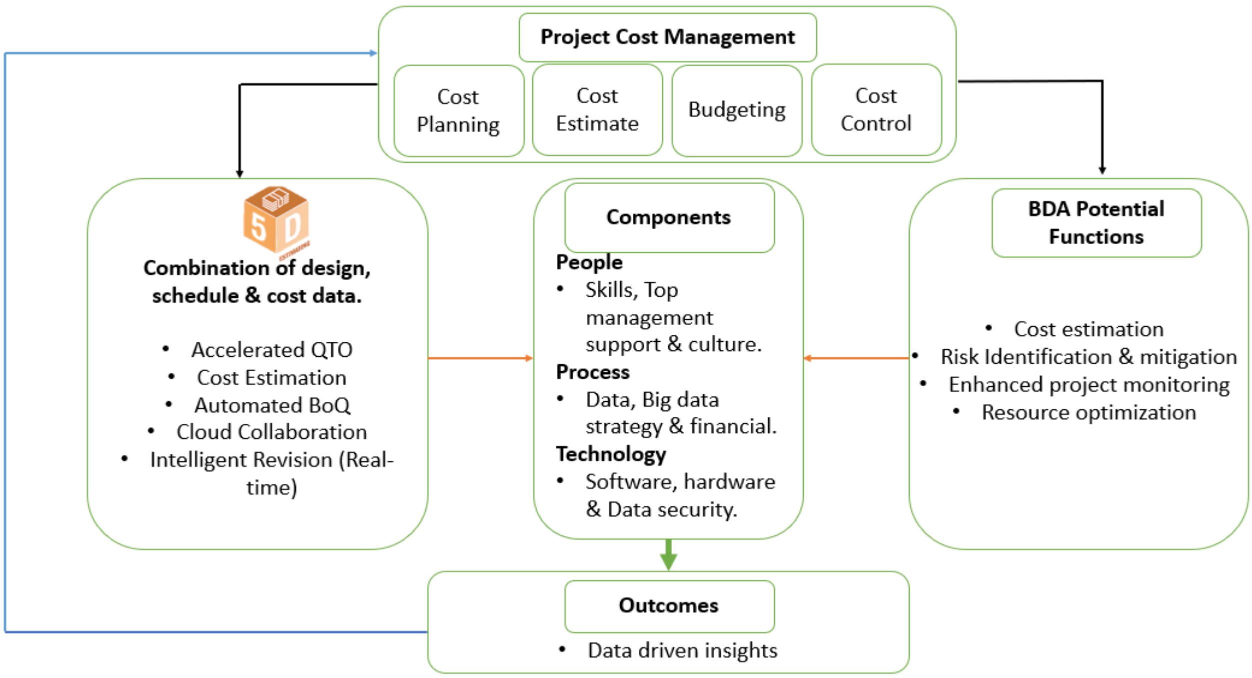


**Figure 7: Theoretical Framework**

Although a potential solution is proposed through the theoretical framework, the scarcity of studies in this area demands further exploration to perform the conformity. Therefore, this research is significant to harness the potential of BDA with 5D BIM to enhance PCM.

## Conclusion

Despite the scarcity of research on 5D BIM and BDA integration in PCM, this paper managed to develop a theoretical framework that serves as a foundation for future empirical study. By synthesizing the existing studies, the framework highlights both the potential and existing functions while identifying the common components required for the practical implementation within the construction sector. Therefore, the need to further advance research in this area is clearly demonstrated through the proposed framework.

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| **Acknowledgements:** | The authors would like to express their sincere gratitude to the Department of Quantity Surveying, Kulliyyah of Architecture and Environmental Design, for providing the necessary resources and support throughout the course of this research. Special appreciation is extended to colleagues and peers who contributed valuable insights and constructive feedback, which greatly enhanced the quality of this paper. |
| **Funding Statement:** | This research received financial support from the International Islamic University Malaysia through the Research Initiative Grant Scheme (Publication) 2025 (P-RIGS25-144-0144). The funding body had no role in the design of the study, data collection, analysis, interpretation of results, or the decision to publish this manuscript. |
| **Conflict of Interest Statement:** | The authors declare that there is no conflict of interest regarding the publication of this paper. All authors have contributed to this work and approved the final version of the manuscript for submission to the Journal of Information System and Technology Management (JISTM) |
| **Ethics Statement:** | This study did not involve any human participants, animals, or sensitive data requiring ethical approval. The authors confirm that the research was conducted in accordance with accepted academic integrity and ethical publishing standards. |
| **Author Contribution Statement:** | All authors contributed significantly to the development of this manuscript. Faris Hyder Ali was responsible for the conceptualization, methodology, and interpretation of the results. Siti Nora Haryati contributed to the critical revision of the manuscript and overall supervision of the study. All authors read and approved the final version of the manuscript before submission. |

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