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Enhancing Cost Management in Construction: The Role of 5D Building Information Modeling (BIM)

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Abstract

Effective cost management is crucial for delivering construction projects within budget constraints. This research presents a comparative analysis of traditional cost management methods and the innovative application of 5D Building Information Modeling (5D-BIM). Traditional practices such as cost estimation, planning, budgeting, and control are explored, revealing their limitations, particularly in dynamic project environments. Our study, through an exhaustive literature review and empirical survey, demonstrates how 5D-BIM offers a transformative approach by enabling real-time visualization and analysis of cost data, thereby enhancing decision-making processes. Key findings reveal that 5D-BIM significantly improves project cost optimization, financial forecasting, and overall decision-making across project lifecycles. The research identifies a notable gap in industry knowledge and application of 5D-BIM, suggesting an urgent need for educational initiatives. Ultimately, this paper advocates for a paradigm shift towards integrating 5D-BIM into traditional cost management practices to harness its full potential in enhancing cost management efficacy in the construction industry.

Keywords: Construction Projects; Cost Management; Cost Estimation; Cost Control; Building Information Modeling; 5D-BIM; Project Lifecycle.

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1. Introduction

The Architecture, Engineering, and Construction (AEC) sector in the UK has been profoundly shaped by the profession of quantity surveying (QS) for nearly two centuries (Cartlidge, 2017). This pivotal role extends across the global AEC industry, encompassing critical project phases from feasibility through to construction and beyond, including facility extensions, refurbishments, and maintenance (Abdelalim et al., 2017), (Abdelalim & Khedr, 2022). In this article, the "construction industry" typically reflects the UK context, whereas the "AEC industry" is more aligned with the terminology used within the US system. Both terms describe the complex network of activities essential for delivering construction projects, with an emphasis on the three foundational stages of project development.

Quantity surveyors, central to this framework, are indispensable as cost managers. Their expertise is crucial not only in the initial stages of project feasibility and design but also throughout the construction process, where they ensure financial and operational efficiency. The importance of robust cost management practices in construction cannot be overstated, as they directly influence the 'Project Management Triangle' cost, time, and quality. These elements are the benchmarks against which project success is measured, underscoring the vital role of QS in achieving balance and efficiency in construction project management (Abdelalim et al., 2019).

This paper explores the integration of 5D Building Information Modelling (5D-BIM) into traditional QS practices, marking a significant shift toward more dynamic, integrated, and efficient cost management processes. This integration promises to not only enhance the traditional roles and responsibilities of QS but also to revolutionize the way cost management is conducted in the AEC industry.

2. The Bibliometric Analysis

Bibliometric analysis serves as a pivotal statistical tool for mapping the state of the art across various scientific domains. This methodology, part of a broader set of bibliometric measures, utilizes diverse approaches such as publication counts, citation analysis, co-citation networks, bibliographic coupling, keyword co-occurrence, and co-authorship networks to assist researchers in identifying relevant and current research issues (Tao et al., 2021). For this study, bibliometric methods and VOS viewer software were employed to conduct a quantitative analysis of existing literature, sourced from the Scopus database, which includes 356 articles on cost management using 5D Building Information Modelling (BIM) up to the year 2023.

The significant corpus of literature indicates a critical shift from traditional cost management methods towards integrated and data-driven approaches facilitated by 5D-BIM. This technology is instrumental in achieving accurate cost estimations, fostering efficient collaboration, and providing a comprehensive understanding of cost implications across project lifecycles. The growing body of research not only reflects a heightened interest in refining cost management practices within the construction industry but also underscores the potentially pivotal role of 5D-BIM in future cost management frameworks.

It is noteworthy that the search criteria for this analysis were meticulously refined to focus on English-language documents within the Engineering and Business subject areas. The selected keywords for this search included 'Project Management,' 'Construction Industry,' 'Costs,' 'Cost Estimation,' 'Cost Control,' '5D-BIM,' 'Construction Projects,' and 'Building Information Modeling.' These terms were instrumental in navigating the extensive databases to extract pertinent information, ensuring that the analysis remained focused on the most relevant studies. The search was quarry structured as follows:

(TITLE-ABS-KEY ("cost management" OR "cost estimation" OR "cost budgeting" OR "cost control" OR "cost plan") AND TITLE-ABS-KEY ("5D" OR "BIM")) AND (LIMIT-TO (

SUBJAREA , "ENGI") OR LIMIT-TO (SUBJAREA , "BUSI")) AND (LIMIT-TO (LANGUAGE , "English")) AND (EXCLUDE (EXACTKEYWORD , "Robotics") OR EXCLUDE (EXACTKEYWORD , "Ontology"))

This targeted search facilitated the extraction of data that most accurately reflects current trends and innovations in cost management practices using 5D-BIM, providing a robust foundation for further discussion and investigation in this research paper.

Figure 1 presents a bibliometric network analysis of keywords sourced from Scopus, demonstrating the interrelation and frequency of topics surrounding Cost Management and 5D-BIM in published literature. This visual representation is particularly illuminating, as it highlights the prominence of specific clusters that encapsulate the core areas of BIM application in construction project management.

The following illustrates each cluster as follows:

Cluster 1: This cluster encapsulates foundational BIM topics like 'construction,' 'cost,' 'design,' 'project management,' and 'sustainability.' It reflects a comprehensive perspective on the diverse elements critical to BIM's successful adoption in construction.

Cluster 2: This cluster focuses on '5D BIM' and its integral components, such as 'cost estimating,' 'procurement,' and 'visualization.' It underscores the importance of applying 5D BIM for precise cost estimation and project visualization, underscoring the multifaceted advantages of advanced BIM technologies.

Cluster 3: Here, the technical facets of BIM technology are examined, emphasizing 'cost control,' 'information management,' and 'lean construction.' This cluster highlights the strategic employment of BIM tools for optimizing project delivery and management.

Cluster 4: It details the 'benefits' and 'implementation' of BIM in the construction sector, highlighting the positive impacts BIM has had on 'construction management,' and suggesting a trajectory for enhanced project outcomes through effective BIM application.

Cluster 5: The final cluster delves into the constructive collaboration between 'building information modeling' and 'quantity surveying.' It accentuates how BIM can improve cost management processes and streamline the role of quantity surveyors in construction engineering.

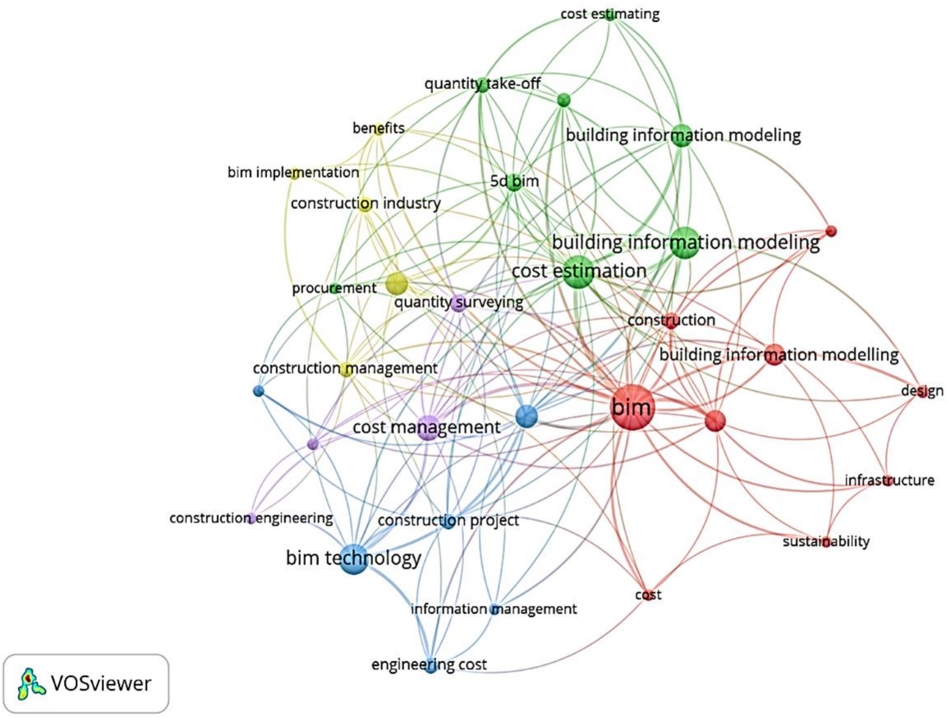

Figure 1. Analysis results of publications by keywords from Scopus.

3. Problem Statement

Within the construction industry, the confluence of Building Information Modeling (BIM) and cost management has heralded a potential change in basic assumptions in project control methodologies. However, the specific integration of the five-dimensional aspect of BIM (5D-BIM), which incorporates cost alongside traditional spatial and temporal dimensions, remains insufficiently explored and understood. This shortfall persists despite 5D-BIM's demonstrated capacity to fundamentally transform cost management protocols by enabling more accurate and timely assessments of actual costs—a critical factor in decision-making and cost overrun mitigation.

As construction projects escalate in complexity, the volume of data necessitated for effective management surges, presenting a challenge in the collection, analysis, and integration of diverse project information (Abdelalim, 2019), (Abdelalim & Hassanen, 2022). The current knowledge gap, compounded by a lack of comprehensive research on 5D-BIM's implementation and benefits in cost management, underscores an industry-wide issue that calls for an integrated system capable of synthesizing information across various project domains (Goedert & Meadati, 2008).

Addressing this lacuna, this paper posits the development of an integrated approach for cost assessment and control as essential for the refinement of project estimation, ongoing monitoring, and overarching control practices. By navigating the intersection of 5D-BIM technology with traditional cost management, the study aims to illuminate pathways for innovation and efficiency in the management of construction projects.

4. Methodology

Employing a mixed-methods research design, this study critically investigates the integration of traditional cost management practices with 5D Building Information Modeling (5D-BIM) in the construction industry. The approach combines a comprehensive literature review with an empirical survey to draw a dual perspective on the subject.

The literature review commenced with an exhaustive analysis of existing scholarly and industry-related literature on cost management and 5D-BIM. This analysis established a theoretical backdrop for understanding the traditional practices of cost management, detailing the processes of cost estimation, planning, budgeting, and control. It also explored the integration benefits and barriers of 5D-BIM within these practices, providing a scholarly foundation for the subsequent empirical investigation.

Advancing to the empirical phase, the study included the development of a survey questionnaire, which was systematically designed to evaluate the construction industry's current understanding and application of 5D-BIM, particularly with cost-related functions. This survey targeted a diverse group of industry professionals, including project managers, quantity surveyors, architects, and engineers, to ensure a representative understanding of the field. The responses were then subjected to statistical analysis, aiming to discern patterns and trends in the adoption and perception of 5D-BIM.

The survey results indicated a pronounced deficit in both knowledge and application of 5D-BIM in industry practices. This gap underscores a need for enhanced education and awareness initiatives about the technology's benefits and potential in cost management. Thus, the study's methodology not only furnishes insights into the current state of 5D-BIM integration but also underscores the pressing need to bridge the knowledge gap for its successful implementation in cost management processes within the construction industry.

5. Cost Management Current Practices

Cost management is the cornerstone of project management, serving as the systematic approach for planning, estimating, budgeting, financing, funding, monitoring, and controlling costs throughout the life of a project. This is detailed in the Project Management Body of Knowledge (PMBOK Guide, 2013), which serves as a key reference in project management practices. In the construction industry, cost management is particularly critical as it entails managing and controlling costs from project inception to final building occupancy and utilization. Ensuring that projects remain within approved budgetary constraints, align with aesthetic and engineering requirements, and are delivered on time and within financial resources, is paramount (Ashworth, 2013).

The role of Quantity Surveyors (QS) is integral at every stage of a project's life cycle, encompassing a variety of tasks from the initial strategic definition to the final close-out and building use. **Table 1,** adapted from the RIBA Plan of Work (Lu et al., 2018), provides a visual representation of these stages and the associated cost management tasks undertaken by QS professionals. These stages include:

Strategic Definition and Preparation & Brief: During these preliminary phases, QS is engaged in project feasibility studies, cost advice, and budget planning, setting the financial foundation for the entire project.

Concept and Developed Design: At these design stages, QS delivers pre-tender cost estimates and advises on alternative materials and construction methods, contributing to design-stage cost plans that can influence the project's economic viability.

Technical Design and Construction: Here, the QS's focus shifts to tendering—preparing costings, tender documents, and bills of quantities, followed by cost control measures during the construction phase.

Handover & Close Out: Finally, QS manages the settlement of final accounts, variations, and feedback for future estimates.

The QS's adaptability and expertise ensure that cost management is a dynamic and responsive process, capable of addressing the diverse challenges that arise throughout a project's development. Cost control becomes particularly critical during the construction stage, where expenditure must be closely monitored and managed (Abdelalim et al., 2023). This involves regular comparison of actual expenditures against the baseline cost plan, preparing valuations and reports, and managing interim payments. **Table 1** not only demystifies QS tasks but also underscores the strategic importance of their role in maintaining the financial health of construction projects.

Through **Table 1** and the accompanying explanations, the paper elucidates the comprehensive nature of cost management tasks as aligned with the different stages of the work, showcasing the pivotal role of QS in achieving project success and financial integrity.

Table 1. Quantity surveyors' tasks and responsibilities align with the RIBA Plan of Work (Lu et al., 2018).

	Work Stages	**Cost Management Tasks**
Preparation	▪ Strategic Definition ▪ Preparation	**Preliminary Cost Estimate** ▪ Project feasibility study ▪ Cost planning & budgeting ▪ Procurement methods
Design	▪ Concept Design ▪ Developed Design ▪ Technical Design	**Design-Stage Cost Plan** ▪ Pre-tender cost estimate and cost plan ▪ Tendering process & Resources identification
Construction	▪ Construction Phase	**Cost Control** ▪ Preparing Cost reports ▪ Payment management ▪ Claims preparing
Use	▪ Handover ▪ In Use	**Variation and Final Account** ▪ Final payment ▪ Lesson learns for next Cost Estimates

5.1. Preliminary cost estimates

At the core of project initiation in the construction industry lies the pivotal responsibility of quantity surveyors (QS) to forecast the expected financial outlay for project execution. This fundamental aspect of cost estimation is indispensable, as it underpins critical project processes such as tendering, contracting, financing, and revenue optimization from the project's inception (Cartlidge, 2013).

During the initial planning phase, QS employs their expertise to conduct comprehensive feasibility studies, guiding clients on the project's financial viability and potential profitability. Preliminary cost estimates, derived at this nascent stage, provide an early financial projection that, while subject to refinement, offers invaluable insights into the anticipated expenses. These estimates consider a spectrum of cost drivers, including land acquisition, construction expenses, operational overheads, site servicing, as well as cash flow and market trends, laying the foundation for a project's financial strategy.

Drawing from a repository of historical data and their extensive professional acumen, QS develops these initial estimates often referred to as top-down, feasibility, or conceptual estimates to establish a preliminary budget. Such initial financial planning is essential for clients, serving as a decision-making tool to evaluate the project's trajectory and feasibility. It's crucial to recognize that these early-stage estimates are iterative in nature, requiring adjustments as project details become progressively refined.

Despite their inherent early-stage uncertainties, these preliminary estimates play a decisive role in the construction process. They not only inform the client's decision on whether to proceed with the project but also provide a basis for subsequent, more detailed cost planning and procurement strategy development as the project transitions to the design phase.

5.2. Design-Stage Cost Plan

The advice of quantity surveyors (QS) during the design stage is crucial in shaping the financial trajectory of a construction project. With the progressive clarity that each phase of design brings, QS can formulate detailed cost estimates for each functional element of the project. Such estimates not only facilitate the economic viability assessment but also rationalize the distribution of the project's budget. This stage may also involve comparative cost estimation to evaluate potential cost-saving alternatives in design materials or methods.

The interactive process of design evolution necessitates timely decision-making to preempt escalating costs due to design changes. **Figure 2** illustrates a pivotal concept from the PMBOK Guide (PMBOK Guide, 2013): the effect of stakeholders' impact, risks, and uncertainty over time, juxtaposed against the cost of design changes. Early design stages allow for greater influence with relatively low-cost implications. However, as the project matures, the cost of making design changes increases significantly, while the ability of stakeholders to affect impactful outcomes diminishes. This graphical representation emphasizes the importance of early and strategic decision-making in managing costs effectively.

QS engagement during the design stage ensures that the cost implications of design decisions are thoroughly evaluated, thereby optimizing cost efficiency. This process, known as design-stage cost planning, encompasses various forms of estimation techniques such as analytical, bottom-up, or bid estimating. These techniques rely on detailed design information and are integral to bid evaluation, contract modifications, and authorization of work scopes. When a Bill of Quantities (BOQ) is furnished, each item is meticulously broken down and analyzed in terms of labor, materials, and machinery costs by the contractor's estimator. This analytical process aids in pinpointing potential cost-saving opportunities and implementing measures to ensure fiscal discipline. A collaborative dynamic between the client, designer, and QS is paramount during this phase to ensure design alterations are addressed promptly, thereby avoiding unnecessary cost increments, and securing the project's overall financial efficiency.

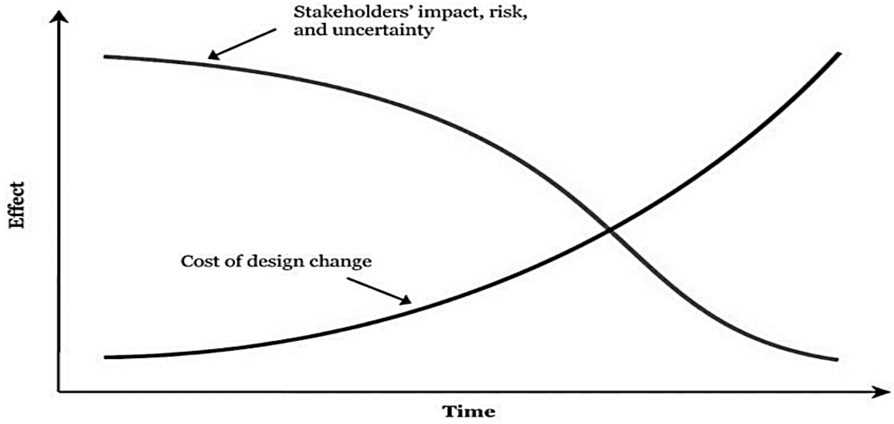

Figure 2. The effect of variables based on project time (Lu et al., 2018).

5.3. Tendering

Following the completion of design drawings, the tendering phase marks a critical juncture in construction project management. Quantity surveyors (QS) are instrumental at this stage, undertaking pre-tender cost estimations and preparing tender documentation for contractor bids. Their analysis of tender submissions is not merely comparative; it involves a strategic evaluation of potential value and risk, informed by a deep understanding of the project's cost components.

As articulated by (Cartlidge, 2013), the tender package is a meticulously crafted collection of documents designed to communicate the project requirements and financial parameters to prospective contractors. Essential elements of this package include:

- **Bill of Quantities (BoQ):** The BoQ serves as the financial nexus of the tender, detailing all material and labor costs. Two copies are provided—one bound for formal submission and one unbound, allowing contractors to disseminate sections to subcontractors for precise pricing.
- **Indicative Drawings:** These drawings, upon which the BoQ is based, offer a visual and technical representation of the project, allowing for accurate contractor pricing.
- **Form of Tender:** This document encapsulates the contractor's formal offer, delineating the bid price and the terms and conditions of the tender.
- **Instructions:** Detailed instructions ensure that submissions are standardized, specifying submission timelines and locations, thereby facilitating an equitable tendering process.
- **Tender Envelope:** A designated envelope for the return of the tender ensures the confidentiality and formal submission of contractor bids.
- **Concept and Developed Design:** At these design stages, QS delivers pre-tender cost estimates and advises on alternative materials and construction methods, contributing to design-stage cost plans.

The BoQ, at its core, is a quantified forecast of the project's physical components, translating design elements into a financial lexicon that forms the basis for contractual agreements. It is a dynamic tool, bridging the gap between conceptual design and tangible construction, and serves as a reference point for financial management throughout the project lifecycle.

The role of the QS in the tendering process extends beyond document preparation. It encompasses a thorough review of tender submissions, evaluating the fiscal and technical feasibility of each bid. This stage is foundational in securing a contractor whose financial proposal aligns with the project's cost estimates and who demonstrates the capability to deliver within the defined scope and quality standards.

5.4. Tendering

During the phase of construction where the expertise of Quantity Surveyors (QS) in cost control becomes imperative. Transitioning from initial estimations to ongoing fiscal management, QS engages in rigorous monitoring of the project's financial health. The essence of cost control lies in aligning the actual expenditure with the client's financial expectations, a process described by the PMBOK Guide (PMBOK Guide, 2013)as being essential for the financial integrity of a project. It entails a continuous assessment of project costs against the cost baseline, addressing any deviations through strategic interventions to prevent budget overruns.

Figure 3 depicts this process graphically, illustrating the relationship between the cumulative actual cost and the baseline over time. It becomes apparent that as the project advances, the actual costs may diverge from the baseline, an indication of financial drift. Such a scenario necessitates immediate corrective measures to realign costs with the budget, reinforcing the role of QS as the financial stewards of construction projects.

Effective cost control is necessitated by the complexities inherent in construction projects, which are often exacerbated by initial planning challenges and the unpredictability of construction costs. QS is responsible for the regular update of cost information, ensuring that all financial records accurately reflect the status of the project. This involves meticulous comparisons between actual expenditures and planned budgets, and the preparation of detailed valuation reports. These reports serve as the basis for managing interim payments and are integral to the role of QS as advisors to clients and project teams, facilitating efficient financial coordination and decision-making.

By employing their analytical acumen, QS can identify potential cost-saving measures, advise on variations, and provide expert guidance on contractual claims. This proactive approach ensures the financial viability of construction projects and the successful achievement of project objectives without compromising the designated budget.

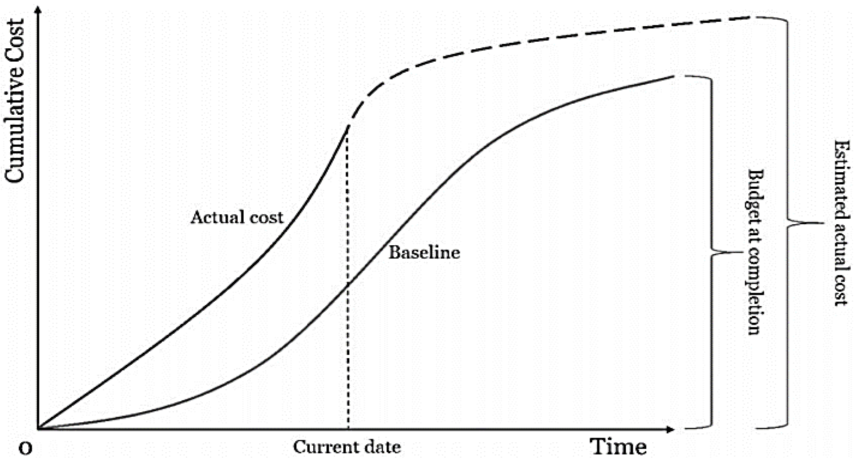

Figure 3. Clarification of the baseline and actual cost (Lu et al., 2018)**.**

5.5. Variations

As construction projects reach completion, the focus of a Quantity Surveyor (QS) shifts towards reconciling the final accounts and managing the settlement of the final payment. This critical stage involves a meticulous evaluation of any deviations or 'variations' from the original cost plan that have been manifested during the construction process. These variations can be attributed to a multitude of factors, including but not limited to, design modifications, changes in work quantities, alterations in project quality standards, evolving working conditions, or adjustments in the sequence of construction tasks. Such fluctuations may stem from advancements in technology, revisions in legal regulations, unexpected geological discoveries, fluctuations in material availability, or shifts in market dynamics.

The process of managing these variations is multifaceted. Contractors are required to report any project changes to the QS through regular updates and site visits, ensuring that all modifications are captured and documented. The QS's role then involves quantifying these changes and assigning value based on current market rates. This exercise is typically followed by a collaborative review with contractors to scrutinize the cost implications and valuations associated with the measured variations.

An integral part of this process is the pursuit of consensus between the QS and contractors on the final account, striving to achieve an agreement that accurately reflects the revised scope of work. While reaching a formal agreement on the final account is not a mandated practice, it is highly recommended and supported by professional QS institutions as a best practice. Such an agreement facilitates transparency and mutual understanding, thereby minimizing disputes and fostering a cooperative project close-out.

The systematic recording of cost data and variation details not only concludes the financial management of the current project but also serves as a valuable database for future cost estimations and project planning. By maintaining comprehensive records, the QS helps to enrich the industry's knowledge base, providing empirical data that can inform the cost management strategies of forthcoming projects.

6. BIM Definition

Building Information Modeling (BIM), as defined by the National Building Information Model Standard - United States (Brianna Crandall, 2023; National BIM Standard, 2023), is a comprehensive digital representation of a facility's physical and functional characteristics. BIM serves as a shared resource of knowledge, pivotal for informed decision-making across a facility's entire lifecycle. Central to the utility of BIM is the concept of interoperability, which encapsulates the ability of diverse systems and organizations to synergistically exchange and leverage information.

Interoperability within the context of BIM is underpinned by the adoption of open data standards, chief among which is the Industry Foundation Classes (IFC). IFC is an open, vendor-neutral data format that standardizes the exchange of building information models, facilitating seamless interaction between the myriads of software applications prevalent in the architecture, engineering, and construction (AEC) industry. This standard is instrumental in ensuring the precision and fidelity of 3D models and their accompanying data across different BIM software platforms and disciplines.

Another cornerstone in the BIM interoperability framework is the Construction Operations Building Information Exchange (COBie). COBie is a specialized format designed to streamline the exchange of building information pertinent to facility management. By structuring data related to building components and systems in a manner that is readily accessible, COBie effectively bridges the gap between the construction phase and subsequent operation and maintenance phases. This standard foster enhanced data stewardship, thereby bolstering decision-making processes throughout the building's lifecycle.

The integration of interoperability standards like IFC and COBie is not merely a technical exercise; it is an enabler of enriched collaboration, improved coordination, and more effective communication among project stakeholders, such integration yields significant advantages, including heightened decision-making acuity, cost efficiencies, and streamlined construction projects (D. Chen et al., 2008).

7. BIM Adoption for Cost Management

In the realm of quantity surveying, the customization of Building Information Modeling (BIM) to meet QS-specific needs culminates in the development of a tailored BIM execution plan. This specialized plan, known as QS-BIM, pinpoints and integrates the unique requirements of cost management within its structure, enabling a more effective application of BIM technology.

The adoption of BIM for cost management hinges on several critical success factors, each of which addresses the nuances and complexities of the QS profession. Paramount among these is the identification of the demand for QS-BIM, which involves a detailed articulation of the desired functionalities that QS professionals require for efficient cost management. These functionalities range from the capability for intricate cost estimation to the facilitation of comprehensive value engineering.

Moreover, successful BIM integration into cost management extends beyond mere technological adoption; it necessitates a culture of collaboration among all project participants. Such collaboration is augmented by the integration of cost data into the BIM model, which ensures that all stakeholders have access to consistent and up-to-date financial information.

Additionally, the standardization of QS processes within the BIM context is vital, establishing clear protocols for data entry, retrieval, and analysis. Training and capacity building form the bedrock of this transition, equipping QS professionals with the necessary skills to navigate and utilize BIM tools effectively.

Furthermore, an adaptable change management strategy is critical to address and mitigate resistance, ensuring a smooth transition to new methodologies. This strategy, coupled with a commitment to continuous improvement, paves the way for ongoing refinement of BIM applications in cost management, aligning with the evolving landscape of the AEC industry.

These factors collectively contribute to the successful implementation of BIM in cost management, leading to enhanced precision, efficiency, and value in the delivery of construction projects (Aibinu & Venkatesh, 2013), (Abdelalim & Shehab, 2023).

8. Possibilities of BIM for Cost Management

The capabilities of Building Information Modeling (BIM) are profoundly reshaping cost management practices in construction projects. When transitioning from the design stage to construction, BIM models are updated from 'as-designed' to 'as-built' status, meticulously reflecting the actual construction details. This 'as-built' BIM becomes an indispensable tool for tracking progress, identifying discrepancies, and integrating variations that emerge during construction. It is an integral part of generating accurate and timely cost reports, thus facilitating rigorous financial control throughout the construction phases (Vigneault et al., 2020).

The precision and reliability offered by BIM in documenting and managing costs are unparalleled, especially when compared to traditional methods, emphasizing the instrumental role of 'as-built' BIM in streamlining the financial management of construction projects, from interim payment calculations to the final settlement (Dang et al., 2020).

As depicted in **Table 2**, BIM offers a multitude of advantages at different stages of the RIBA Plan of Work. This visual tool outlines the spectrum of tasks and responsibilities of Quantity Surveyors (QS) and demonstrates how BIM facilitates and enhances each of these stages. From the initial strategic definition, where BIM aids in preliminary cost estimates and feasibility studies, to the technical design and construction phases, where it supports tendering and cost control, BIM enhances the QS's capability to deliver accurate and informed cost management (Lu et al., 2018).

In the final stages of the project, BIM continues to prove invaluable. The comprehensive data within the 'as-built' BIM model ensures that the final accounts reflect the true scope of the work completed, incorporating any variations accurately. For Quantity Surveyors, the 'as-built' BIM provides a definitive, data-rich platform to generate the final account, ultimately fostering a more efficient handover and close-out process.

Table 2 elucidates how the integration of BIM into QS tasks streamlines workflows and injects a higher level of accuracy and efficiency into the cost management process. By embracing BIM, QS professionals can offer stakeholders a more transparent, dynamic, and robust management service throughout the lifecycle of a construction project.

Table 2. According to BIM implementation, QS' tasks, and responsibilities (Lu et al., 2018).

	Work Stages	Cost Management Tasks	BIM Utilization
Preparation	▪ Strategic Definition ▪ Preparation	**Preliminary Cost Estimate** ▪ Project feasibility study ▪ Cost planning & budgeting ▪ Procurement methods	▪ Develop & organize schematic BIM ▪ Link with the Cost Database
Design	▪ Concept Design ▪ Developed Design ▪ Technical Design	**Design-Stage Cost Plan** ▪ Pre-tender cost estimate and cost plan ▪ Tendering process & Resources identification	▪ Develop & integrate design information ▪ QTO ▪ Cost plan ▪ Tender documents and specifications
Construction	▪ Construction Phase	**Cost Control** ▪ Preparing Cost reports ▪ Payment management ▪ Claims preparing	▪ BIM as-built ▪ Tracking progress & variations ▪ Cost Reports
Use	▪ Handover ▪ In Use	**Variation and Final Account** ▪ Final payment ▪ Lesson learns for next Cost Estimates	▪ Developing as-is BIM

9. BIM Execution Plan for Cost Management

A meticulously developed BIM Execution Plan (BEP) is paramount for the efficacious adoption of BIM in AEC projects. This strategic document delineates a framework that clarifies the roles, responsibilities, and contributions of all project stakeholders in BIM processes. As a dynamic guide, the BEP facilitates a shared understanding amongst owners, architects, engineers, contractors, and facility managers, ensuring cohesive action towards common project goals.

The formulation of the BEP is critical during the early stages of a project, ensuring that BIM-related activities are integrated into the project workflows from the outset. This foundational strategy encompasses coordination of the project's vision, objectives, and protocols, thus serving as a cornerstone for BIM implementation. An effective BEP also specifies the resources and technologies required, while establishing benchmarks for monitoring and measuring BIM's impact on the project's success (Shawky et al., 2024), (Abdelalim & Abo.elsaud, 2019).

According to the "BIM Execution Planning Guide" (Messner et al., 2019), the creation of a BEP is most successful when it involves a collaborative effort among all key project participants. This inclusivity not only fosters commitment but also leverages the collective expertise essential for addressing the multifaceted dimensions of BIM deployment. The ensuing subsections will unpack the critical steps endorsed by industry best practices for formulating a robust BEP, from initial conceptualization to its operational execution.

The 5D-BIM Execution Plan is a strategic approach that encompasses a series of well-defined stages and tasks, integral to the successful management of construction projects. The Quantity Surveyors (QS) play an instrumental role in this plan, leveraging BIM to optimize cost management throughout the project lifecycle. Below is a synthesized overview of the key stages and associated tasks, as influenced by QS involvement and BIM utilization (Lu et al., 2018), (Abdelalim et al., 2020):

- **Stage 0 - Strategic Definition:** QS begins by developing preliminary cost estimates and design-stage cost plans. This initial stage involves creating a schematic BIM model (LOD 100) and interfacing it with external cost estimation tools like CostX, Glodon, and Solibri Model Checker. The goal is to establish an initial financial framework for the project (Hussain et al., 2024).

- **Stage 1 - Preparation and Brief:** As the project definition consolidates, QS enhances the BIM model's detail (LOD 200-350), organizing and integrating design information. They conduct quantity take-offs and extend prices, resulting in detailed cost plans that inform budget allocation and procurement strategies.
- **Stage 2 - Tendering:** In the tendering phase, the BIM model evolves to reflect the designed intent (LOD 300-400). The QS prepares tender documentation, ensuring it reflects project specifications and client requirements. The BIM model aids in extracting planning parameters and generating detailed quantities for tendering purposes.
- **Stage 3 - Construction:** During construction, QS focus shifts to cost control. Advanced BIM technologies are utilized for tracking progress and managing variations, enabling QS to perform interim payment assessments, variation valuations, and manage contractual claims. Regular cost reports are generated from the BIM model, maintaining financial transparency and control.
- **Stage 4 - Handover and Close Out:** The as-built BIM model (LOD 300-400) is finalized, incorporating all construction variations. This model provides a digital representation of the completed project and becomes a critical tool for the final account settlement and facility management handover.
- **Stage 5 - In Use:** Upon project completion, the QS remains engaged in the operational phase, ensuring that the BIM model continues to serve as a management asset.

At every stage from one to four, the QS interacts with diverse information flows, which include specifications, assembly items, pricing, and a robust project cost database. Contractual documents and predefined cost thresholds are meticulously associated with the BIM model to facilitate variation detection and management. The execution plan mandates a continuous loop of information exchange, employing data from the BIM model, design and shop drawings, financial statements, and progress reports to inform decision-making (Vigneault et al., 2020).

Moreover, the QS bears the responsibility of formulating regulations and specifications for QS BIM, determining measurement standards, and advising on the development of both the QS BIM model and its underlying database. This continuous improvement ethos extends to refining tools for cost and contract management grounded in BIM methodologies.

The effective integration of BIM during this phase ensures that operational efficiencies and maintenance strategies are supported by comprehensive data and insights from the construction phase. This systematic approach, documented in the 5D-BIM Execution Plan, aligns with the Levels of Development (LOD) framework, ensuring that the model's fidelity meets the needs of each project phase. By leveraging BIM, QS professionals are equipped to navigate and manage the complexities of modern construction projects, delivering precise cost management and robust financial stewardship from inception to operation.

10. Benefits of Using BIM-5D

The integration of BIM 5D into construction project management represents a transformative advancement over traditional cost estimation methods. Its primary advantage lies in fostering a collaborative environment where stakeholders and project teams converge on a unified working platform, enhancing their involvement and influence in decision-making processes. BIM 5D acts as a catalyst for increasing project productivity, optimizing time and financial resources, and facilitating smoother project execution (Hadi Mustafa et al., 2023).

One of the fundamental strengths of BIM 5D is its capacity to visually depict the project's development at the pre-construction stage through 3D modeling. This capability is critical in preempting and addressing project management challenges, thereby streamlining construction workflows, and enhancing overall procedural efficiency (Chan et al., 2019), (Migilinskas et al., 2013) and (Hasan & Rasheed, 2019).

The tangible benefits realized during both pre-construction and construction phases post BIM 5D implementation (Lotliker, 2021):

- **Streamlined Cost Estimation and Forecasting:** BIM 5D simplifies the complex process of cost estimation, providing accurate and dynamic forecasting capabilities.
- **Comprehensive Quantity Take-Off:** It facilitates an exhaustive and precise extraction of quantities directly from the model, thereby minimizing errors and assumptions.
- **Facilitated Information Exchange:** The platform enhances the exchange of information, ensuring all parties have access to current and relevant project data.
- **Improved Collaboration through Project Visualization:** The visual nature of BIM 5D models promotes an inclusive and collaborative approach among stakeholders, enhancing communication and understanding.
- **Ease of Incorporating Changes:** BIM 5D allows for fluid integration of changes into the model, reflecting real-time adjustments with immediate visibility of cost implications.
- **Refined Project Sequencing and Scheduling:** The model incorporates time-related data (4D), aligning cost variables with the project timeline to optimize scheduling.
- **Cost and Risk Reduction:** By providing a holistic view of the project, BIM 5D enables stakeholders to identify and mitigate risks proactively, leading to cost savings.
- **Elevated Project Quality:** The detailed and coordinated approach intrinsic to BIM 5D contributes to enhancing the overall quality of the construction project.
- **Competitive Edge in Project Delivery:** The comprehensive insights and efficiency gains offered by BIM 5D bolster the project's competitiveness in the market.

The adoption of BIM 5D, therefore, not only refines current practices but also sets a new standard for how cost management is conducted within the AEC industry. The empirical benefits observed testify to BIM 5D’s pivotal role in delivering construction projects that are cost-effective, timely, and of superior quality (Banihashemi et al., 2022), (K. Chen & Fang, 2024), (Abdelalim & Salah Omar M. Said, 2021).

11.Questionnaire Analysis

The structured questionnaire designed for this study was formulated to critically analyze the industry's proficiency in and adaptation to 5D-BIM for cost management. It encompassed 38 questions, strategically categorized to elicit comprehensive insights from respondents. These categories included:

- Respondent Profiles: A set of five questions aimed at capturing the demographic and professional backgrounds of the participants, providing context to the responses and allowing for a segmented analysis of the data.
- Core Competencies in Cost Management: The subsequent questions were tailored to assess the respondents’ expertise in cost management skills, with a focus on discerning the level of integration of BIM 5D in current practices.
- Cost Estimation and Quantity Takeoff: Questions in this category explored the respondents' methodologies in cost estimation and the extent to which BIM 5D has influenced accuracy and efficiency in quantity takeoff procedures.

- Cost Control: This section delved into the participants' approaches to maintaining financial integrity throughout a project's lifecycle, comparing traditional practices with those augmented by BIM 5D.
- Collaboration and Communication: Here, the questionnaire evaluated the impact of BIM 5D on interdisciplinary communication and project collaboration.
- Training and Adoption: Respondents provided insights into the training processes they underwent for BIM 5D, and the challenges and successes associated with its adoption.

Each phase of the cost management process was paired with a knowledge assessment, juxtaposing conventional methodologies against the capabilities offered by 5D-BIM. This comparative analysis aimed to uncover the degree of improvement or alteration in practices attributed to BIM 5D adoption.

The aggregated data from the questionnaire will be subject to rigorous statistical analysis to quantify the influence of 5D-BIM on cost management. This includes testing for correlations between BIM 5D utilization and reported improvements in cost estimation accuracy, project delivery, and stakeholder satisfaction. The analysis aims to substantiate the theoretical benefits of 5D-BIM with empirical evidence derived from industry professionals' experiences.

11.1. Sample Size

The determination of the representative sample size was grounded in statistical theory to ensure the reliability of the study findings. The sample size was calculated to reflect the confidence level and margin of error suitable for this research by Utilizing the formulae presented (Abdelalim et al., 2023):

$$ss = \frac{z^2 * p * (1-p)}{e^2} \quad (1)$$

SS: (calculated sample size)

Z: value for the confidence level (e.g. 1.64 for 95% confidence level)

p = percentage picking a choice, expressed as decimal (0.2 used for sample size needed)

e = confidence interval, expressed as decimal (e.g., 0.08 = ±8%)

With an engineer population in the Egyptian construction industry estimated at 860,000, the calculated sample size was determined to be 68, after applying a correction for a known population size.

$$ss = \frac{1.64^2 * 0.2 * (1-0.2)}{0.08^2} = 68$$

$$SS_{corr} = \frac{ss}{1 + \frac{ss-1}{pop}} \quad (3)$$

$$SS_{corr} = \frac{68}{1 + \frac{68-1}{860000}} = 68 \quad (4)$$

The survey, distributed to 150 engineers, garnered 96 valuable responses within a two-month period. This response rate provides a robust dataset from which to draw insights into the adoption and impact of BIM 5D on cost management in the AEC industry.

Respondent Experience:

As depicted in **Figure 5,** most respondents (46) have less than 5 years of experience in the AEC industry, followed by 31 respondents with 5-10 years of experience. This distribution indicates a healthy mix of both new professionals, likely to be more familiar with the latest technological trends such as BIM, and experienced practitioners who offer insights into traditional cost management practices.

Organization Type:

Figure 4 illustrates the diversity of organization types represented in the survey responses. A significant majority of respondents (56) belong to contractor organizations, followed by 21 from consultancy services. The data shows that the survey reached a broad cross-section of professionals, ensuring that the findings are reflective of the industry.

Data Analysis:

To ensure a comprehensive analysis, the survey results will be dissected using various descriptive graphical methods, charts, and figures. This approach aims to visually convey the data, aiding in the interpretation of patterns and trends relating to BIM 5D adoption and its effect on project management, particularly risk assessment, and mitigation.

In conclusion, the sample size and respondent profile present a comprehensive picture of the current state of BIM 5D utilization in the Egyptian construction sector. The findings derived from this survey are anticipated to offer valuable contributions to the body of knowledge regarding BIM's role in enhancing cost management practices.

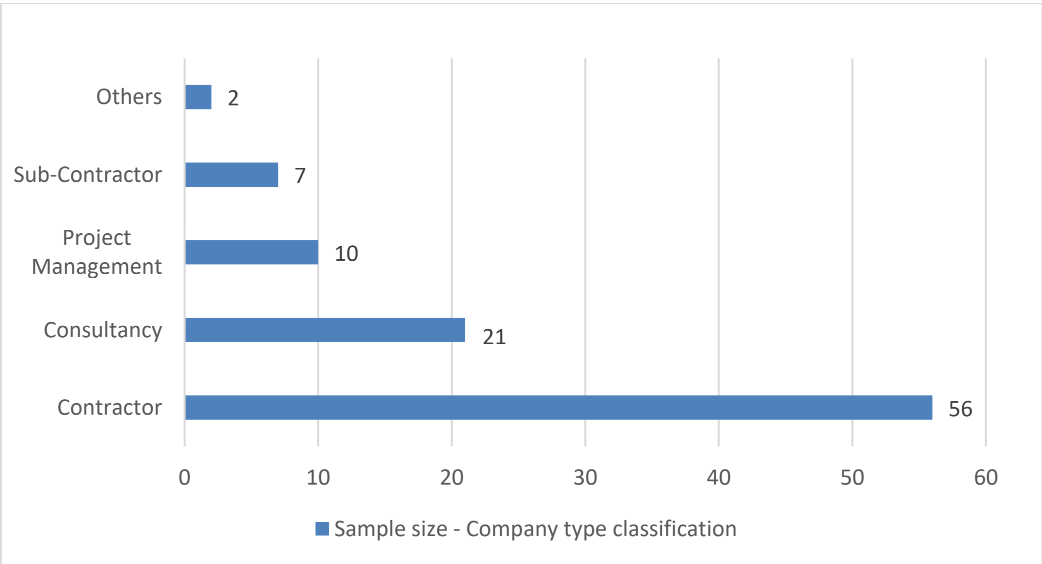

Figure 4. Company's main business activity.

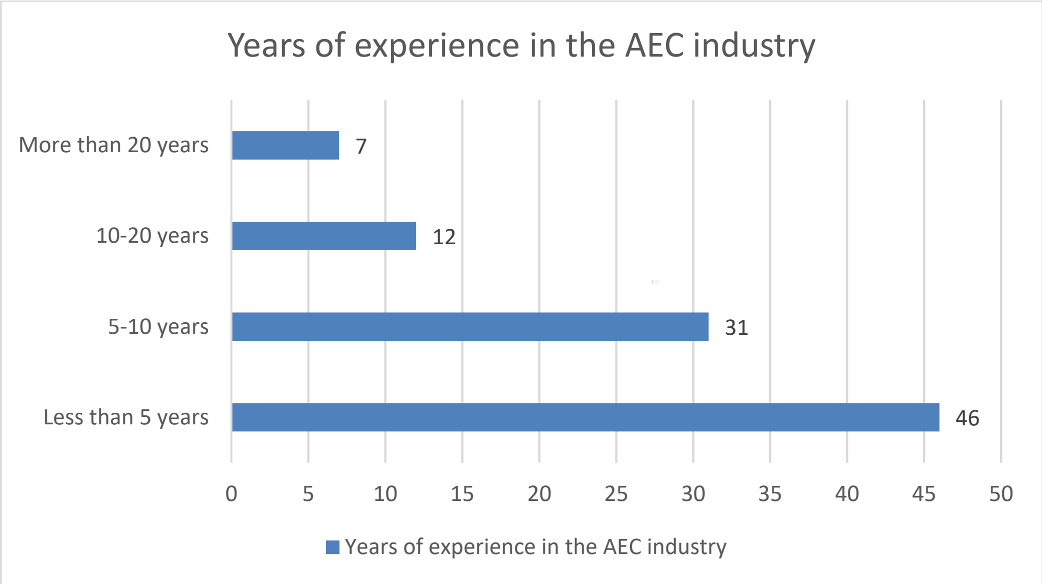

Figure 5. Years of experience in the AEC industry.

11.2. Reliability Analysis

To ascertain the internal consistency of the questionnaire items and thereby confirm the reliability of the constructs within this study, a statistical evaluation was undertaken using Cronbach's alpha coefficient and the Corrected Item-Total Correlation. Cronbach's alpha is a measure of scale reliability, or in other words, it gauges the degree to which a set of items are related as part of a group, providing an index of the coherence of the scale.

An alpha coefficient of 0.7 is posited as the threshold for acceptable reliability. Factors yielding a Corrected Item-Total Correlation below 0.3 are deemed unreliable and are typically excluded from the scale to improve consistency, according to the following criteria (Kien, 2012).

In the current study, the overall Cronbach's Alpha value achieved is 0.877, as indicated in **Table 3**, which exceeds the acceptable benchmark. This high value suggests a superior level of internal consistency among the survey items.

Table 3. Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
0.877	0.874	14

The reliability analysis thus validates the robustness of the questionnaire. With a Cronbach's Alpha value surpassing 0.8, the survey instrument employed in this research demonstrates excellent reliability, ensuring that the results and subsequent analyses are founded on a statistically sound basis. This high level of scale reliability reinforces the validity of the conclusions drawn from this study and underscores the precision of the insights into BIM 5D's role in cost management within the AEC industry.

11.3. Sample Size

The statistical approach employed to discern the relationships between different facets of traditional and BIM 5D cost management practices in this study involves the Pearson correlation coefficient. This method offers a quantifiable insight into the direction and magnitude of associations between variables.

The correlation coefficient (R) is as follows :

R = 0 indicates no correlation.

R < 0.1 implies a weak correlation.

0.3 > R > 0.1 indicates a moderate correlation.

0.5 > R > 0.3 suggests a strong correlation.

R > 0.5 denotes a very strong correlation.

A significance level (α) of 0.05 was adopted, corresponding to a 95% confidence level.

Familiarity and Proficiency in Cost Management:

- The correlation between familiarity with traditional cost management and BIM 5D cost management, as presented in **Table 4**, showed a positive, albeit moderate, correlation coefficient of 0.140 with a significance (p-value) of 0.175. This indicates that respondents who are familiar with traditional cost management are slightly more inclined to be familiar with BIM 5D cost management, though not significantly at the conventional 0.05 alpha level.
- A similar analysis is extended in **Table 5** concerning proficiency. Here, the correlation coefficient is 0.268, indicating a moderate positive correlation between proficiency in traditional cost management and BIM 5D cost management. This correlation is significant at the 0.01 level with a p-value of 0.008, signifying that as proficiency with traditional methods increases, so does proficiency with BIM 5D, to a moderate extent.

Tolerance to Changes in Cost Estimation Methods:

- The analysis regarding the tolerance of traditional and BIM 5D cost estimate methods to changes, as seen in **Table 6**, yields a weak correlation coefficient of 0.079 with a p-value of 0.443. This suggests that there's only a slight, non-significant tendency for respondents who find traditional methods adaptable to changes to also perceive BIM 5D methods as adaptable.
-

Effectiveness in Keeping Costs Within Budget:

- In
- **Table 7**, the focus shifts to the effectiveness of maintaining budget constraints. Here, we observe a moderately significant correlation coefficient of 0.291, with a p-value of 0.007. This indicates that respondents who view traditional cost control methods as effective in keeping costs within budget also find that cost control using BIM 5D is effective to a moderate degree.

Capturing Potential Cost Savings:

- The correlation between the traditional and BIM 5D cost control in capturing potential cost savings, reflected in **Table 8**, shows a coefficient of 0.147. While this represents a positive correlation, it's weak and not statistically significant (p-value of 0.174), implying a negligible relationship between the perceived ability of both methods to realize potential cost savings.

Holistic Impact of BIM 5D on Cost Management:

- Lastly, in **Table 9**, a more comprehensive analysis regarding BIM 5D's overall impact on cost management is conducted. A very strong and significant positive correlation of 0.599 (p-value < 0.001) is noted for the level of accuracy in using BIM 5D. This indicates a robust relationship between the accurate implementation of BIM 5D in cost management and capturing potential cost savings.

- Furthermore, the time savings in exporting smart sheets according to 5D methodology have a strong and significant positive correlation of 0.466 with BIM 5D cost savings (p-value < 0.001), highlighting that time efficiency in BIM 5D processes is closely associated with cost savings.
- The correlations also reveal areas that may require further attention, such as the correlation between the level of training and adoption of BIM 5D in organizations and the ability to foresee the future of cost management, which shows a weak and non-significant relationship. This implies that while respondents may recognize the benefits of BIM 5D, there is still a gap in training and adoption that, if addressed, could bolster the capacity to predict and adapt to future cost management trends.

In essence, the Pearson correlation core analysis elucidates the dynamic interplay between familiarity, proficiency, adaptability, and effectiveness across traditional cost management and BIM 5D methodologies. It reveals a spectrum of strengths where BIM 5D is making a measurable impact, as well as highlighting areas where increased training and adaptation are necessary to fully leverage BIM 5D's capabilities.

Table 4. Pearson correlation coefficient between the level of familiarity with traditional and BIM 5D cost management methods.

		Are you familiar with traditional cost management methods used in the AEC industry?	Are you familiar with BIM 5D cost management?
Are you familiar with traditional cost management methods used in the AEC industry?	Pearson Correlation	1	.140
	Sig. (2-tailed)		.175
	N	96	96
Are you familiar with BIM 5D cost management?	Pearson Correlation	.140	1
	Sig. (2-tailed)	.175	
	N	96	96

Table 5. Pearson correlation coefficient between the level of proficiency in traditional and BIM 5D cost management methods.

		What is your level of proficiency in traditional cost management methods?	What is your level of proficiency in BIM 5D cost management methods?
What is your level of proficiency in traditional cost management methods?	Pearson Correlation	1	.268**
	Sig. (2-tailed)		.008
	N	96	96
What is your level of proficiency in BIM 5D cost management methods?	Pearson Correlation	.268**	1
	Sig. (2-tailed)	.008	
	N	96	96

**. Correlation is significant at the 0.01 level (2-tailed).

Table 6. Pearson correlation coefficient between how tolerant the use of traditional and BIM 5D cost estimate methods to make changes.

		In your opinion, how tolerant is the use of traditional Cost Estimate methods to make changes?	In your opinion, how tolerant the use of BIM 5D Cost Estimate methods to make changes?
In your opinion, how tolerant is the use of traditional Cost Estimate methods to make changes?	Pearson Correlation	1	.079
	Sig. (2-tailed)		.443
	N	96	96
In your opinion, how tolerant is the use of BIM 5D Cost Estimate methods to make changes?	Pearson Correlation	.079	1
	Sig. (2-tailed)	.443	
	N	96	96

Table 7. Pearson correlation coefficient between the effectiveness of traditional and BIM 5D cost management methods in keeping project costs within budget.

		How effective is the traditional cost control in keeping project costs within budget?	How effective is cost control using 5D BIM in keeping project costs within budget?
How effective is the traditional cost control in keeping project costs within budget?	Pearson Correlation	1	.291**
	Sig. (2-tailed)		.007
	N	96	86
How effective is cost control using 5D BIM in keeping project costs within budget?	Pearson Correlation	.291**	1
	Sig. (2-tailed)	.007	
	N	86	86

**. Correlation is significant at the 0.01 level (2-tailed).

Table 8. Pearson correlation coefficient between How well does the traditional and BIM 5D cost control capture potential cost savings.

		How well does traditional cost control capture potential cost savings?	How well does cost control using 5D BIM capture potential cost savings?
How well does traditional cost control capture potential cost savings?	Pearson Correlation	1	.147
	Sig. (2-tailed)		.174
	N	96	87
How well does cost control using 5D BIM capture potential cost savings?	Pearson Correlation	.147	1
	Sig. (2-tailed)	.174	
	N	87	87

Table 9. Pearson correlation coefficient between five items for BIM 5D cost management.

		How well does cost control using 5D BIM capture potential cost savings?	What is the level of accuracy in using 5D BIM technology in Cost Management?	What is the level of time-saving in exporting smart sheets according to 5D methodology?	What is the level of training and adoption of BIM 5D in your organization?	In your opinion, how do you foresee the future of cost management in the AEC industry? Will BIM 5D become the standard? Why or why not?
How well does cost control using 5D BIM capture potential cost savings?	Pearson Correlation	**1**				
	Sig. (2-tailed)					
	N	**87**				
What is the level of accuracy in using 5D BIM technology in Cost Management?	Pearson Correlation	**.599****	**1**			
	Sig. (2-tailed)	**.000**				
	N	**84**	**86**			
What is the level of time-saving in exporting smart sheets according to 5D methodology?	Pearson Correlation	**.466****	**.684****	**1**		
	Sig. (2-tailed)	**.000**	**.000**			
	N	**87**	**86**	**96**		
What is the level of training and adoption of BIM 5D in your organization?	Pearson Correlation	**.088**	**.058**	**.096**	**1**	
	Sig. (2-tailed)	**.420**	**.594**	**.086**		
	N	**87**	**86**	**96**	**96**	
In your opinion, how do you foresee the future of cost management in the AEC industry? Will BIM 5D become the standard? Why or why not?	Pearson Correlation	**.294****	**.374****	**.169**	**.012**	**1**
	Sig. (2-tailed)	**.006**	**.000**	**.099**	**.905**	
	N	**87**	**86**	**96**	**96**	**96**

****. Correlation is significant at the 0.01 level (2-tailed).**

11.4. Mann-Whitney U-Test

The Mann-Whitney U Test serves as a non-parametric alternative to the independent sample t-test when the dependent variable does not conform to a normal distribution within the groups being compared. The primary utility of this test is in evaluating the ranks of two independent samples to deduce if they come from the same distribution. t assesses the ranks of two independent samples to determine if they originate from the same population.

Test of Normality:

The initial step involved testing for normality using both the Kolmogorov-Smirnov and Shapiro-Wilk tests, as detailed in **Table 10**. The significance level from these tests (Sig. 0.000) decisively falls below the conventional alpha threshold ($\alpha = 0.05$), leading to the rejection of the null hypothesis (H0) that posits data distribution is normal. This validates the choice of employing the Mann-Whitney U Test for further analysis.

Mann-Whitney U Analysis:

The subsequent analysis compares the knowledge and application of traditional cost management methods with that of BIM-5D across three key domains: Cost Management, Cost Estimation, and Cost Control.

- **Cost Management Comparison:** In **Table 11**, traditional cost management methods and BIM-5D are compared. The Mann-Whitney U value of 2975 and a significant Z-score of -4.980 with an asymptotic significance (2-tailed) of less than 0.001 indicate a significant difference between the two groups. This suggests that traditional cost management knowledge and BIM-5D knowledge are not equivalent within the sampled population.
- **Cost Estimation Comparison:** As shown in **Table 12**, the analysis for cost estimation methods reveals a Z-score of -4.457 with a significance level of less than 0.001, affirming that traditional cost estimation knowledge differs significantly from that of BIM-5D.
- **Cost Control Comparison: Table 13** focuses on cost control methods. The Z-score here is -6.332, with a significant level of less than 0.001, indicating a significant difference between traditional and BIM-5D cost control knowledge and practices.

Interpretation and Implications:

The consistent findings across **Table 11**, **Table 12** and **Table 13** demonstrate a substantial disparity in the knowledge and implementation of traditional cost management methods versus BIM-5D within the industry. The lower mean rank for BIM-5D-related questions suggests that, while BIM-5D may be known among industry professionals, it is less familiar or implemented when compared to traditional methods.

This discrepancy points to an opportunity within the industry for enhanced training and education on BIM-5D to bridge the knowledge gap. Furthermore, the significant positive correlation between BIM-5D familiarity and cost management effectiveness implies that increased adoption of BIM-5D could lead to better cost control outcomes in construction projects.

In conclusion, the Mann-Whitney U Test results underscore a prevailing inclination within the construction industry toward traditional cost management practices, with BIM-5D yet to achieve the same level of penetration. Addressing this lacuna presents a strategic avenue for industry-wide progression, advocating for a shift in focus towards BIM-5D to harness its full potential in enhancing cost management processes.

Table 10. Test of Normality.

Tests of Normality

	groups	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
knowledge	traditional	.382	96	.000	.700	96	.000
	5D	.337	96	.000	.784	96	.000

a. Lilliefors Significance Correction

Table 11. Comparison of Cost Management Methods.

Ranks

CODE	N	Mean Rank	Sum of Ranks
Traditional Method	96	113.51	10897.00
5D-BIM	96	79.49	7631.00
Total	192		

Test Statistics[a]

Mann-Whitney U	2975.000
Wilcoxon W	7631.000
Z	-4.980
Asymp. Sig. (2-tailed)	<.001

Table 12. Comparison of Cost Estimation Methods.

Ranks

CODE	N	Mean Rank	Sum of Ranks
Traditional Method	96	79.66	7647.50
5D-BIM	96	113.34	10880.50
Total	192		

Test Statistics[a]

Mann-Whitney U	2991.500
Wilcoxon W	7647.500
Z	-4.457
Asymp. Sig. (2-tailed)	<.001

a. Grouping Variable: CODE

Table 13. Comparison of Cost Control Methods.

Ranks

CODE	N	Mean Rank	Sum of Ranks
Traditional Method	96	70.02	6722.00
5D-BIM	87	116.25	10114.00
Total	183		

Test Statistics[a]

Mann-Whitney U	2066.000
Wilcoxon W	6722.000
Z	-6.332
Asymp. Sig. (2-tailed)	<0.001

a. Grouping Variable: CODE

12. Conclusion

The extensive data analysis, anchored by Pearson Correlation and the Mann-Whitney U tests, has shed light on a pivotal industry juncture: the integration of BIM within cost management is at crossroads. Despite the entrenched reliance on traditional cost management techniques, the empirical evidence points to a stark reality that a considerable divide in knowledge and utilization of BIM, especially within the 5D scope, persists in the industry.

Proficiency in conventional methods remains undisputed, with many professionals demonstrating a strong command over established practices like cost estimation and control. However, the study surfaces a critical revelation: there is an untapped potential in 5D-BIM technology that is yet to be fully harnessed, hindered by a significant knowledge gap and insufficient organizational training and adoption.

Respondents have acknowledged the existence of advanced 5D-BIM software tools such as CostX, Glodon, Synchro, and Navisworks that could revolutionize cost management. Yet, these remain underutilized, and the benefits they offer are not fully realized in current industry practice

13. Recommendations

It is imperative to champion a renaissance in the construction industry a movement toward fully embracing the capabilities of 5D-BIM. To this end, we recommend a two-pronged strategy:

Firstly, initiating comprehensive awareness programs that delineate the tangible benefits of 5D-BIM, aimed at dispelling misconceptions and enlightening professionals about the efficiency gains and accuracy improvements it promises.

Secondly, an educational overhaul is required. Rigorous training programs must be instituted, ensuring that the intricacies of 5D-BIM are not only understood but seamlessly integrated into the daily workflows of cost management.

By converging on these focal points, the construction industry can leap forward, bridging the current knowledge divide. The adoption of 5D-BIM stands as a beacon for progress, signaling an era where cost estimation and control are not just about maintaining budgets, but about pioneering practices that spell success in bold letters.

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