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BIM Application in Life-Cycle Cost Management of Construction Projects

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Abstract. With the development of the construction industry, the traditional cost management model for construction projects is increasingly inadequate to address the challenges of modern engineering. Life-cycle cost management provides a new approach for construction project cost management, and BIM technology can effectively enhance its quality and efficiency. However, BIM technology still faces some obstacles in practical application, and its advantages are not being fully exerted. This paper summarizes the application advantages of BIM technology in life-cycle cost management of construction projects, analyzes the synergistic effect of BIM in cost management workflow, summarizes the obstacles encountered in the application of BIM technology in practical cost management, and attempts to propose several coping strategies. The fundamental reason why BIM technology can effectively enhance the efficiency of cost management lies in its collaborative capabilities at the three levels of information carrier, data processing, and management process. The main obstacles encountered in the application of BIM technology include the obstruction of workflow integration, high application costs, and data distortion blockage. This can be addressed by cultivating compound talents, improving the existing workflow, and enhancing information sharing during the working process. The findings of this study provide valuable insights for both researchers and practitioners, and aim to promote the development of BIM life-cycle cost management.

Keywords: Building Information Modeling (BIM); Life-cycle Cost Management; Construction Projects; Collaboration; Implementation Barriers.

1. Introduction

1.1. Research Background

In construction projects, cost management has a crucial impact on the economic and social benefits of the project. With the rapid development of the construction industry, current construction projects are becoming increasingly diverse and complex. This puts forward new demands for the cost management model. However, the traditional project cost management model is plagued by problems. These problems, such as information silos, poor multi-party collaboration, data integration hurdles, and forecasting inaccuracies, underscore the limitations of the traditional cost management model. Applying cost management throughout the life cycle of construction projects can effectively control the total cost throughout the project's entire life cycle, which provides a new strategy for cost management in construction projects.

Building Information Modeling (BIM), as a data tool for construction management, can help reduce the time and effort spent on cost management, enhance productivity, and save costs [1]. BIM technology has been widely studied and applied in life-cycle cost management of construction projects [2]. It can integrate information, process data, and conduct visual management throughout the project's entire life cycle, thereby enhancing the quality and efficiency of full life cycle cost management [3]. However, despite extensive research, BIM technology still encounters significant barriers in practical implementation. Consequently, its potential advantages are not fully realized, leading to low resource utilization rates. For instance, this often manifests as cost overruns due to inaccurate data exchange or delays stemming from inefficient collaboration between design and construction teams. There is still a certain degree of isolation between each stage and each party involved in the project [4]. Therefore, it is still necessary to study the application practice of BIM technology in life-cycle cost management of construction projects, as well as the problems and corresponding strategies encountered in the engineering practice. Based on this, this paper analyzes BIM implications and barriers in construction projects and puts forward corresponding countermeasures.

1.2. Literature Review

The application of BIM technology in life-cycle cost management of construction projects has been widely discussed. Kehily and Underwood proposed that by embedding the life cycle costing model into CostX 5D BIM software, the efficiency of cost estimation using BIM technology is improved, providing a new solution for the application of BIM technology in life-cycle cost management [5]. Zanni et al. incorporated the Integrated DEFinition (IDEF) 3 structured diagramming modeling technique into a software model and developed a model for a systematic approach for BIM-supported Whole Life Cost assessment based on CE principles, which has the potential to enhance life-cycle cost management [6]. Yang uses BIM technology combined with the earned value method to distinguish routes and establish a cost management model, which helps to control the cost deviation accurately during the project implementation process and has an early warning control and correction effect [7]. Hu Jia proposed a cost control strategy for the entire life cycle of construction projects based on BIM technology, and it effectively reduces the total project cost by designing a dynamic cost monitoring mechanism, promoting cooperative management among all project parties, and establishing a risk prevention system [8].

The application method of BIM in life cost management has been widely studied, and its advantages have been fairly reflected. The synergistic mechanism of BIM technology in each stage of life-cycle cost management has been studied to a certain extent, too. However, the deficiencies encountered by BIM technology in engineering practice haven't been adequately represented in the literature above, and there is a lack of an integrated summary and elaboration in this aspect.

This paper seeks to fill this gap by providing a systematic analysis of these implementation barriers and proposing actionable strategies to overcome them, which constitutes a primary contribution of this research.

1.3. Research Framework

Under the above background, the research framework of this paper is as follows. First, this paper summarizes the application status and advantages of BIM technology in each stage of life-cycle cost management under the research background of BIM implication in construction projects. An actual engineering case is presented to provide better analysis. Then, it analyzes the synergistic effect of BIM technology in life-cycle cost management. This part is divided into three aspects: information carrier, data processing, and project management. Finally, it points out some barriers and problems existing in the application of BIM technology and attempts to propose possible optimization methods. This study aims to provide a reference for subsequent research and to improve the development of BIM applications in life-cycle cost management.

2. BIM Application in Construction Projects Cost Management

2.1. Application in the Decision and Design Stage: Enhancing Early-Stage Precision

The decision stage and the design stage are fundamental for ensuring the quality of the projects. Traditional project cost management emphasizes construction while neglecting preparatory work in the design stage. The implementation of investment planning and cost control in the early stage is not in place; the design work and cost control lack relevance, and too much emphasis is placed on the rationality of the design itself [4].

In BIM mode, BIM technology is used to establish a building information model, and the cost information is associated with the model. With the help of the model, decision-makers can estimate the cost and engineering quantity of different schemes to improve efficiency and make accurate investment predictions; designers can quickly carry out collision inspection, quota design, and timely adjustment to improve the preliminary work [9]. This is facilitated by the parametric modeling capability of BIM, where a change in the design automatically updates all associated views and quantities. This greatly reduces resulting engineering changes and ensures the quality and speed of preliminary cost management work. This contrasts sharply with the traditional approach, where late-stage error detection leads to costly rework and delays.

2.2. Application in the Bidding and Tendering Stage: Improving Quantity Take-off Accuracy

During the bidding and tendering process, accurately calculating the quantities is crucial. Manual calculation often requires a large amount of personnel and time to ensure the accuracy of the results. In contrast, utilizing data from BIM models, the quantities can be calculated quickly to compile an accurate bill of quantities. Project participants involved in the tendering process can obtain more detailed and intuitive information through BIM models as references for bidding and tendering work.

2.3. Application in the Construction and Completion Stage: Enabling Dynamic Control

The construction stage, with the largest investment, is a crucial period for the life-cycle cost management of architectural projects. In traditional cost management systems, there are problems such as information silos, low information processing efficiency, and difficulties in multi-party collaboration. This is due to the large number of participants and the incompatibility of the software, methods, and standards applied. On the contrary, BIM technology employs a unified and shared information model, facilitating coordination and information exchange among all parties involved in the project. The model also provides a powerful tool for dynamic cost control. Thus, BIM serves as a crucial tool for enhancing cost management efficiency during the construction phase.

The completion and delivery stage, as the stage for settlement and confirmation, is equally important. The BIM model contains complete information, such as material usage and construction changes during the construction process, which reduces the time needed for information integration. Therefore, the implementation of BIM can significantly improve the accuracy and efficiency of the settlement process, mitigating financial waste associated with cumbersome procedures and unnecessary verification tasks.

2.4. Application in the Operation and Maintenance Stage: Optimizing Long-Term Value

After the delivery of a construction project, the cost expenditure during its operation and maintenance stage cannot be ignored either. In fact, applying BIM technology for management during the operation and maintenance stage of buildings can help save a significant amount of cost [10]. The visualization and unified management of buildings can be achieved through information models. The management platform enables overall control, data analysis, and efficient implementation of maintenance activities.

2.5. Case Study: Validation through a Commercial Plaza Project

The case selected is a comprehensive commercial plaza project in a certain city in China. This project is in the center of the city, with a total land area of 15,800 m2 and a total construction area of 68,500 m2 [11]. This project serves as a compelling example that demonstrates the integrated application of BIM across all life-cycle stages, as discussed in the previous sections.

Based on BIM technology, the project constructed an integrated cost management model with functions of design scheme cost prediction, engineering quantity intelligent extraction, construction process cost control, and life-cycle data analysis [11]. Through this model, the project achieved quantitative assessment of cost-influencing factors, identification of special structures, automatic extraction and dynamic update of engineering quantities, dynamic cost accounting during the construction process, multi-dimensional cost early warning, and identification of differentiated cost characteristics [11]. Thus, this project can conduct information interaction and data processing throughout its entire life cycle, controlling project cost. Ultimately, the model helped the project reduce the prediction error rate by approximately 3.4%, increase the efficiency of engineering quantity extraction by 223.1%, improve the accuracy of cost control by 61.1%, and lower the total project investment by 3.53% compared to the plan [11].

In summary, the most significant advantage of BIM implementation lies in the intelligence and visualization of the building information model, as well as its collaborative ability to break down information barriers among stages and parties involved in the project. A detailed analysis of this ability will be conducted in the next section.

This case underscores the significant potential of BIM in achieving integrated life-cycle cost management, while also highlighting areas for future enhancement, such as broader collaboration platform usage, which will be discussed later.

3. Synergy of BIM Technology in Life-Cycle Cost Management

The synergy of BIM technology in life-cycle cost management is not achieved through a single feature, but through a profound integration at multiple levels. This synergy can be deconstructed into three interconnected dimensions: the information carrier, data processing, and project management. The following sections analyze how synergy is generated at each level.

3.1. Synergy through a Unified Information Carrier

The BIM model serves as a unified and continuous information carrier, which is fundamental to enabling collaboration across various stages of cost management.

In traditional cost management, the fundamental reason for the isolation of each stage of a project lies in the incompatibility of the methods used by personnel at each stage and in all aspects, as well as the discontinuity of engineering information. For instance, engineering information is scattered across various forms and documents. However, in the actual implementation of the project, all parties are required to apply the scattered information to a unified engineering practice simultaneously. During this process, problems may arise. The software utilized by various participants may exhibit incompatibility. One party may fail to apply the drawings by the other directly. Once events similar to the above two situations occur, information conversion is required. During the implementation of an engineering project, typical information conversion processes include calculating quantities based on design documents, drawing construction drawings based on design drawings, etc. In addition, if the information about a certain part of the project is changed, all the information associated with it needs to be manually modified and confirmed. This process often consumes plenty of time and manpower, which is unfavorable for cost management. In stark contrast, the parametric nature of the BIM model ensures that any change made to an element automatically propagates to all related views, drawings, and schedules, eliminating manual updates and associated errors.

In the BIM environment, engineering information is stored on a unified building information model. All participants collaborate on this model and its associated accessory models. For instance, the quantities and the diagram of a certain plane of a building can be directly extracted from BIM models in BIM software. Project managers can intuitively comprehend the current progress of the project through the BIM models. The changes in engineering information can also be reflected in the model in a timely manner to ensure all participants are informed in real time.

To sum up, as an information carrier, the uniformity of the model ensures the uniformity of engineering information, and the real-time nature of the model guarantees the real-time nature of information transmission. These advantages fundamentally avoid information silos and lay the foundation for BIM’s collaborative effect. This effectively establishes the BIM model as a single source of truth for the project, which is a prerequisite for seamless collaboration and reliable cost management.

3.2. Synergy through Automated and Intelligent Data Processing

Building upon the unified information carrier, the synergy of BIM is further amplified at the data processing level. In the BIM model, each structure is an object containing relevant engineering information. The entire model encompasses most of the data needed in the engineering process, providing a unique data source for cost management work. At the level of data processing methods, BIM technology mainly has two advantages: automation and intelligence.

BIM technology can assist in the automated data processing of cost management work. Information about the building is integrated into a three-dimensional model. Among them, the calculation of quantities can be carried out automatically. The update and association of data are real-time and accurate. Tables and lists can be generated automatically. These can reduce labor costs and enhance efficiency and quality of life-cycle cost management.

BIM has achieved intelligent processing of data. In conventional cost management, the process of drawing conclusions and making predictions from data needed to be done manually, and its accuracy and efficiency were relatively low. Integrating BIM with disciplines such as artificial intelligence, big data, and the Internet of Things to build various intelligent models based on BIM technology can achieve functions such as risk early warning, scheme optimization, and facility diagnosis. This method has higher efficiency and accuracy.

3.3. Synergy through Collaborative and Visual Management

The synergies at the information and data levels are ultimately realized through a transformative shift in the project management paradigm. The BIM model provides a collaborative working platform throughout the entire life cycle of a project. Its visualization makes the management process intuitive and clear.

The work platform in the BIM environment is collaborative. In previous cost management, communication among all parties was linear, requiring multiple layers of transmission from document to document and from person to person. Through BIM, work results are fed back in real time, and data can be accessed and utilized at any time. This collaborative working mode greatly improves communication efficiency and reduces management difficulty.

The management process is visual. The model relates to engineering information, enabling the engineering situation to be directly reflected in the model. This provides managers with an intuitive management objective.

In life-cycle cost management, such a management model significantly reduces the difficulty of decision-making. The project is effectively controlled throughout the entire process. Management costs are reduced. Within the budget, the quality of the project implementation has been greatly improved.

In conclusion, the synergy of BIM stems from the interplay of a unified information carrier, intelligent data processing, and a collaborative management platform. The information carrier ensures data consistency and continuity, which in turn enables automated and intelligent data processing. The processed information is then delivered through a visual and collaborative management platform, ultimately empowering informed decision-making and efficient control throughout the project life cycle. This multi-level synergistic framework is the fundamental reason why BIM can significantly enhance the efficiency and effectiveness of life-cycle cost management.

4. Barriers in BIM Implementation and Corresponding Strategies

4.1. Barriers in BIM Implementation

4.1.1. Resistance to workflow transformation.

Even in the context that BIM technology has been widely used in engineering practice, the BIM model and existing engineering implementation process are still not fully integrated. From the perspective of enterprises and employees, the workflow they used in the past needs to be adaptively changed for BIM technology. This poses two main problems.

Firstly, it is unrealistic to change the workflow of construction enterprises in a short period of time since it often involves complex benefits. Enterprises need to rearrange personnel and work planning. Even if the economic cost of completing these measures is not considered, enterprises also need to take careful consideration of the time cost. As a result, many construction enterprises do not have a strong willingness to carry out workflow reform, or even if the reform is carried out, the degree is not sufficient. Thus, the superiority of BIM technology has not been fully exerted. In fact, in China, according to previous studies, the negative treatment of enterprises is one of the significant factors influencing the blocked application of BIM technology [12].

Secondly, the personnel involved in the project do not always have both BIM skills and cost management skills required for construction projects. The adaptability of these personnel to the workflow under the application of BIM also needs to be considered. In this case, whether it is training the old personnel or introducing new talents, there needs to be a corresponding time and economic expenditure. The subjectivity of workers also makes it difficult to implement the principles of transparency and sharing required by the BIM model.

4.1.2. High initial investment and the talent gap.

To apply BIM technology in engineering, enterprises should make a corresponding investment. The application cost of BIM technology is mainly composed of the following three aspects: software purchase, equipment purchase, and personnel training. The expenditure on these three aspects is not negligible for construction enterprises. Even if the economic budget of the enterprise is sufficient, it will take a certain amount of time to deploy software equipment and train personnel. During this time, the benefits of the enterprise will be affected. In the long term, the application of BIM technology can improve efficiency and save costs for enterprises, but in the short term, after the BIM application, the benefits it brings to enterprises may not be significant. Technological transformation has great risks and uncertainties, which are not acceptable to all enterprises. Additionally, the complexity of BIM technology increases the difficulty of its application. BIM technology puts forward new requirements for cost work. Staff need to master both cost management skills and BIM software operating ability. A previous survey shows that the lack of professional talent is one of the biggest influences on the blocked application of BIM technology [12]. This means that enterprises often need to pay more costs in terms of personnel.

4.1.3. Data interoperability and flow challenges.

Although in an ideal case, the information integration and automatic processing ability of BIM eliminates the isolation between the cost management work of each stage, in actual practice, the compatibility and fluidity of data still need to be improved.

In terms of compatibility, there are many types of BIM software commonly used at present, such as ArchiCAD, Revit, etc., but it cannot be guaranteed that all participants use the same software and data format. Although IFC and other open standards help workers to transform data between different software, the distortion of information is still a problem that cannot be ignored in cost management work under BIM mode.

In terms of liquidity, the linear workflow of traditional project cost management lacks comprehensive change in BIM mode. For example, ideally, the cost personnel should get involved in the design phase to correlate, integrate, and calculate the cost information according to the BIM model completed by the designer. However, in real cases, because the original linear workflow has not been changed, the BIM model is often delivered to the cost personnel after the completion of design, and the data accuracy and data format in the model cannot be guaranteed. This hinders the flow of data. This directly leads to cost estimation inaccuracies, delays in change order management, and ultimately, cost overruns during construction and operation.

4.2. Corresponding Strategies

4.2.1. Strategic workflow re-engineering.

The existing BIM life-cycle cost management workflow may still need some changes. This is not merely a technical adjustment but a shift towards Integrated Project Delivery (IPD) principles, emphasizing early involvement and shared risk/reward. Due to various reasons, the existing BIM mode cannot completely avoid the influence of traditional modes and mindset, but the resistance to change needs to be overcome. For the existing workflow, a more comprehensive review can be conducted to find the key points that contribute to the obstacles in the application of BIM technology. More research is needed in the future for specific improvement methods.

4.2.2. Developing an interdisciplinary talent pipeline.

As a tool, one of the key points for BIM technology to play its advantages lies in the users, that is, the cost management workers themselves. Therefore, cultivating interdisciplinary talents proficient in both cost management and BIM technology is a critical strategy. Talent cultivators are not limited to construction companies. Fundamentally speaking, colleges and universities are the main institutions that cultivate the above-mentioned compound talents. Construction enterprises can strengthen their cooperation with colleges and universities, so that the training of talents can better serve the engineering practice.

4.2.3. Building an integrated data environment.

It has been pointed out in the previous section that BIM technology still has room for improvement in data integration and information collaboration. Since it is unrealistic to require all participants to use the same software and a consistent data format, more work could perhaps be done to enhance information sharing between participants and stages. Among them, strengthening the connection between BIM software and cost software, and developing a more unified and efficient information sharing platform in engineering practice can be regarded as two effective methods. This entails advocating for and adopting open BIM standards (e.g., IFC, COBie) to ensure data interoperability rather than relying on proprietary formats.

5. Conclusion

5.1. Key Findings

This paper, by summarizing existing research and combining with engineering practice, elaborates on the application of BIM technology in life-cycle cost management of construction projects. It first summarizes the application process and advantages of BIM technology in each stage of life-cycle cost management. Combined with actual engineering cases, the role of BIM technology is further illustrated. BIM technology has demonstrated its superiority in practical applications. By applying BIM technology in life-cycle cost management, the project cost can be effectively reduced, and the efficiency of cost management can be improved. Subsequently, it analyzes the synergy of BIM technology, which is mainly reflected in three aspects: the uniformity and continuity of information carriers, the intelligence and automation of data processing, and the synergy and visualization of management processes. Finally, this paper presents the obstacles to the application of BIM technology and attempts to propose several countermeasures.

There are three main barriers to the practical application of BIM in engineering. The first is inadequate integration with existing workflows. The main reason is that the integration of BIM mode and existing cost management mode requires enterprises and employees to make certain changes, which they. Second, the application cost of BIM technology is high, but the short-term return is small. Third, due to practical reasons, BIM software and data form cannot be completely unified, so that BIM technology cannot fully play the compatibility and liquidity advantages of data. The corresponding strategies proposed in this paper mainly include strengthening the training of compound talents, improving the existing work process, and strengthening information sharing in the work process.

5.2. Research Significance

This paper points out the advantages and current obstacles to the application of BIM technology and attempts to propose directions for a solution. This paper plays a role in promoting the application optimization of BIM technology in the field of construction engineering cost. Theoretically, it constructs a multi-level framework for understanding BIM's synergy. Practically, it provides a clear diagnosis of implementation barriers, offering stakeholders a prioritized agenda for improvement. The limitation of this paper lies in the lack of quantitative analysis of the application effect of BIM technology and the gap between the ideal situation and the actual application effect in projects.

5.3. Limitations and Future Study

Additionally, this paper does not use primary data. The paper merely presents several directions for solutions to the obstacles encountered by BIM technology and does not conduct research or discussion on specific approaches.

Future research can quantitatively analyze the gap between the application effect of BIM technology under ideal conditions and in engineering practice. More detailed and in-depth research should be conducted on the solutions to the obstacles proposed in this article to provide further guidance for finding the optimization direction of BIM technology.

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