Scholar Publishing Group
International Journal of Engineering Technology and Construction
https://doi.org/10.38007/IJETC.2024.050109
ISSN 2789-7176 Vol. 5, Issue 1: 78-86

The Application of BIM in the Whole Life Cycle Management of Subway Projects

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Keywords: BIM; Subway Project; Full Life Cycle Management; Collision Detection

Abstract: In the current management of subway projects, problems such as information islands, poor communication and waste of resources are often faced, which seriously affect the efficiency and quality of the project. In order to solve these problems, this paper aims to study the application of building information modeling (BIM) in the full life cycle management of subway projects. This paper first establishes a BIM model to integrate the design, construction and operation information of the project. Secondly, BIM technology is used for collision detection and collaborative design to ensure real-time sharing of information between various disciplines. Then, BIM is used to visualize the construction progress and optimize resource allocation. Finally, BIM is used for operation and maintenance management and digital archives are established. The research results show that by applying BIM technology, the construction period of subway projects is as low as 33 days and the resource utilization rate is as high as 72%. The application of BIM technology in the full life cycle management of subway projects has significantly improved the efficiency and coordination of the project, and provided a management model for future subway construction.

1. Introduction

Modern urban construction accepts subways as one of the most significant public transport systems. In this way, the construction management will have to face a new set of challenges. Gradually, issues have revealed themselves, such as information islands, poor communication, resource wastage, delays, and such problems affecting construction quality and resource efficiency. That is why a more efficient model for management is being sought by subway management. The introduction of Building Information Modeling (BIM) technology might provide new ideas and opportunities to address these issues.

This paper intends to look into all methods aimed aimed at optimizing the full life cycle of management subway projects through BIM technology. In the first place, the study establishes a

BIM model as an integration of the design, construction and operational information of the project so as to remove the information islands phenomenon. Secondly, through the utilization of BIM technology for collision detection and collaborative design, it ensures that information can be shared between disciplines in real-time, thus improving team collaboration efficiency. Then, BIM is used to visualize the construction progress and optimize resource allocation and improve construction efficiency. Finally, BIM is also used for operation and maintenance management, and digital archives are established to enhance subsequent facility management capabilities. The application of these research methods not only helps to improve the level of intelligent project management, but also provides support for the sustainable development of subway construction.

In terms of the structure of the paper, first, in the second part, the relevant research and application status of BIM technology are reviewed, and the shortcomings in the current subway project management are analyzed. The third part introduces the research methods in detail, including the establishment of BIM model, collision detection and collaborative design, construction progress visualization and specific implementation steps of operation and maintenance management. The fourth part focuses on the analysis of changes in key indicators such as construction cycle, resource utilization and failure rate. Finally, the conclusion part summarizes the research results and discusses the application prospects and possible improvement directions of BIM technology in future subway project management.

2. Related Work

In the context of the growing development of urban transportation, the management and technology application of subway construction are particularly important. Based on a newly built subway line in Beijing, Li et al. [1] analyzed the carbon emissions of rail transit throughout its life cycle, established a carbon emission calculation model for the entire line and the entire life cycle of rail transit, and quantitatively calculated the carbon emissions of the entire line and the entire life cycle of the newly built subway line. At the same time, the carbon reduction measures in the construction and operation stages were analyzed and their carbon reduction potential was quantitatively evaluated. Zhen [2] took the planning and construction of the Wuhan Metro BIM full life cycle digital platform as an example to explain how Wuhan Metro is accelerating the integrated application of building information modeling (BIM) technology in the entire process of planning, surveying, design, construction and operation and maintenance of Wuhan's rail transit projects, and realizing data sharing and information management of the entire life cycle of rail transit project construction projects. Shen et al. [3] took the aluminum alloy body structure of a Type B subway vehicle with a maximum operating speed of 120 km/h as an example, conducted dynamic stress testing and load characteristics research based on the preliminary assessment of the weak positions of the body, and evaluated the life status of key positions of the body with equivalent acceleration as input. Su [4] conducted a comprehensive analysis of the key contents of technical management by studying the various stages of the subway project design life cycle, providing effective solutions and guiding technologies to help subway engineering companies learn from them during the operation and production process and reduce large-scale rework or unnecessary investment costs in later operations. Luo et al. [5], based on the concept of subway full life cycle management, explained the automated monitoring technology and intelligent monitoring system, relying on a subway station, combined with the characteristics of the project, discussed the monitoring content, measurement point layout, etc., and proposed the design principles of subway project monitoring solutions, providing a new perspective for subway project safety monitoring. Zhang et al. [6] evaluated the global warming potential of different subway-related earthwork recycling and landfilling options by combining a life cycle assessment model based on field surveys with a life cycle assessment software database. Zhang et al. [7] aimed to deepen the understanding of the factors affecting the safety of subway construction projects in China, with the overall goal of reducing the accident rate. Ghanbaripour et al. [8] revealed CSF in subway construction projects and contributed to the literature on project delivery success, focusing on the perspectives of contractors. Liu et al. [9] proposed a projection pursuit model based on quantum particle swarm optimization for the evaluation of waterlogging resilience of subway station projects. Luo et al. [10] aimed to evaluate the construction safety risks of prefabricated subway stations in my country and formulate corresponding countermeasures to ensure construction safety. These studies provide important theoretical support and practical guidance for the management and sustainable development of subway projects.

3. Methods

3.1 Data Integration and Information Sharing

This paper collects design data from various disciplines during the design phase of the project, including structural, electromechanical, and civil engineering information. By using BIM software, these data are imported into a unified platform to form a multi-dimensional three-dimensional model. The model not only contains the geometric information of the building, but also integrates material properties, construction technology, and related engineering quantity information. This design allows staff to work together on the same platform and update and share information in real time [11]. During the construction phase, the application of BIM models makes information sharing in the construction process more efficient. The construction team can use the model to perform collision detection and discover potential problems in the design in advance, thereby avoiding construction delays caused by design defects. This process ensures that various projects can be efficiently connected by simulating the construction sequence and process flow. Construction personnel can view and update progress information directly on the BIM platform, record changes at the construction site in real time, and feed this information back to the model to form a dynamically updated construction file. During the operation and maintenance phase, the integrated BIM model can provide comprehensive facility management support. The operation team can obtain equipment maintenance information, maintenance records, service life and other data through the model to establish a digital asset management system. In this way, operators can perform daily maintenance and management more efficiently and improve the efficiency of facility use. The establishment of the BIM model not only promotes the integration of design, construction and operation information, but also realizes information sharing between stages.

3.2 Collision Detection and Collaborative Design

Collision detection aims to identify conflicts between designs in different disciplines, such as structure, electromechanical, and civil engineering. By importing the 3D models of various disciplines into the BIM platform, the system can automatically analyze the overlapping and interfering areas in the model, thereby detecting potential problems in advance [12]. The collision detection method is based on the intersection test of geometric bodies. Through this method, the design team can identify and solve problems in a timely manner before construction, avoiding construction delays and increased costs caused by design conflicts. Collaborative design builds on quality from the idea of real-time communication and information sharing among the competing disciplines. All participants can make design changes and optimizations to an equivalent BIM model in order to ensure coordination on the design plan. For example, when the electromechanical department alters pipework, other departments are notified of the changes in real-time so they can make adjustments accordingly based on the new information. While this approach enables sharing documents and collaborating more effectively by enforcing version control and real-time updates [13], in practice, these cloud-based BIM platforms can further enhance collaborative design capabilities. Designers, engineers, and construction workers can have access to model data and modify it in real time via the Internet, so every team member can make a decision based on the same information.

3.3 Visual Management of Construction Progress

Through building information modeling (BIM) technology, the project team can dynamically monitor and manage the construction progress, optimize resource allocation, and improve construction efficiency. The BIM platform can combine the construction progress with the three-dimensional model, providing an intuitive visual display, so that project participants can understand the progress of each construction stage at a glance. In actual application, the BIM system can display the construction progress in a variety of ways such as Gantt charts, progress bars, and three-dimensional animations. For each construction task, the system can update the progress in real time, display the completed part and the remaining workload, and help managers make timely decisions. The BIM platform can also integrate resource information, including the use of personnel, equipment, and materials, to optimize resource allocation [14]. When a process is delayed, the system can automatically adjust the schedule of subsequent processes to ensure that the overall construction progress is not affected. Table 1 shows the construction progress and resource allocation of a subway project at different stages:

Table 1: Construction progress of a subway project at different stages

Stage	**Planned Start Date**	**Planned End Date**	**Actual Completion Status**	**Resource Utilization (%)**
Foundation Work	2024-01-01	2024-02-15	90%	85
Structural Work	2024-02-16	2024-04-30	75%	80
MEP Installation	2024-05-01	2024-07-15	50%	70
Interior Finishing	2024-07-16	2024-09-30	20%	75
Equipment Debugging	2024-10-01	2024-11-30	0%	60

As can be seen from the table, the actual completion of the foundation construction phase reaches 90%, and the resource utilization rate is 85%, indicating that the construction progress of this phase is relatively smooth. However, the completion of the structure construction phase is only 75%, and the resource utilization rate also drops to 80%, suggesting that managers need to pay attention to subsequent resource allocation and scheduling.

3.4 Operation and Maintenance Management

Through BIM, the project team was able to achieve comprehensive digital management of subway facilities, including equipment information, maintenance records, and operating manuals. This integrated information management method not only improves the accessibility of information, but also improves the efficiency and accuracy of maintenance work. BIM can integrate detailed information on various assets, including equipment model, installation location, maintenance cycle, and warranty status. The BIM system can record and update maintenance activities in real time[15]. When performing equipment inspection or maintenance, relevant personnel can directly record maintenance results, failure causes, and repair measures on the BIM platform. This information will form a complete maintenance history archive. Through data analysis, the operation team can identify equipment with high failure rates and optimize maintenance strategies. For example, if the failure rate of a certain equipment exceeds the preset threshold, more frequent inspections and preventive maintenance measures can be taken.

4. Results and Discussion

4.1 Experimental Design and Implementation Steps

In this chapter's experiment, BIM technology is compared with traditional subway project management methods. Two groups of projects are selected for analysis: one group is managed using BIM, and the other group uses traditional methods. The comparison indicators include construction period, resource utilization, and failure rate. The experiment will be conducted in the same subway project environment to ensure that the project scale, geographical location, and construction team are similar to eliminate the influence of external variables. During the construction period, the data of various indicators will be recorded regularly to ensure the accuracy and completeness of the data. Next, the experimental comparison process will be implemented. The progress of the two groups of projects will be monitored at different stages of construction using regular evaluations. The visual management function of the BIM system is used to track the construction progress in real time and record relevant data. After the experiment, the collected data will be analyzed. Through statistical analysis tools, the various indicators of the two groups of projects are compared to evaluate the impact of BIM technology on construction progress and operation and maintenance management.

4.2 Construction period

Different subway projects are selected and managed using BIM technology and traditional project management methods. The construction cycle is tested, and the data is shown in Figure 1:

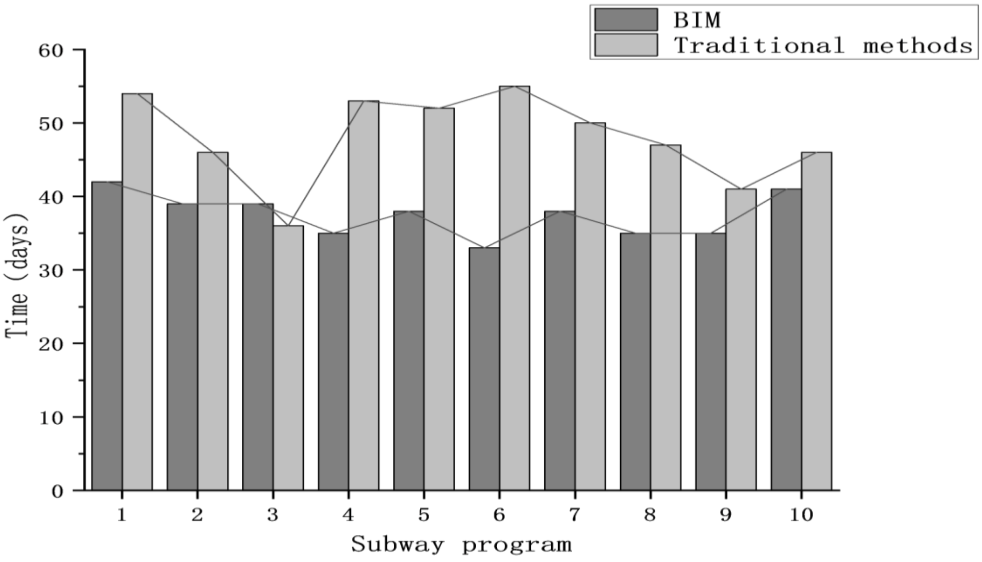

Figure 1: Construction cycle

In all 10 projects, the construction period of the BIM method ranges from 33 days to 42 days, while the construction period of the traditional method ranges from 36 days to 55 days. The average construction period of BIM projects is 38.1 days, while the average construction period of traditional projects is 46.6 days. This shows that BIM has significant advantages in improving construction efficiency. Through real-time data sharing, collision detection and visual management, BIM technology significantly reduces information islands and communication barriers in the construction process, and reduces the incidence of design changes and construction errors. These factors accumulate and ultimately lead to a shortened construction period. BIM technology has significantly improved construction efficiency and shortened the construction period in the management of subway projects, indicating its importance in modern engineering management. Although traditional methods perform well in individual projects, in most cases, the advantages of BIM methods are obvious.

4.3 Resource Utilization

The same test is performed on resource utilization, and Figure 2 shows the test results:

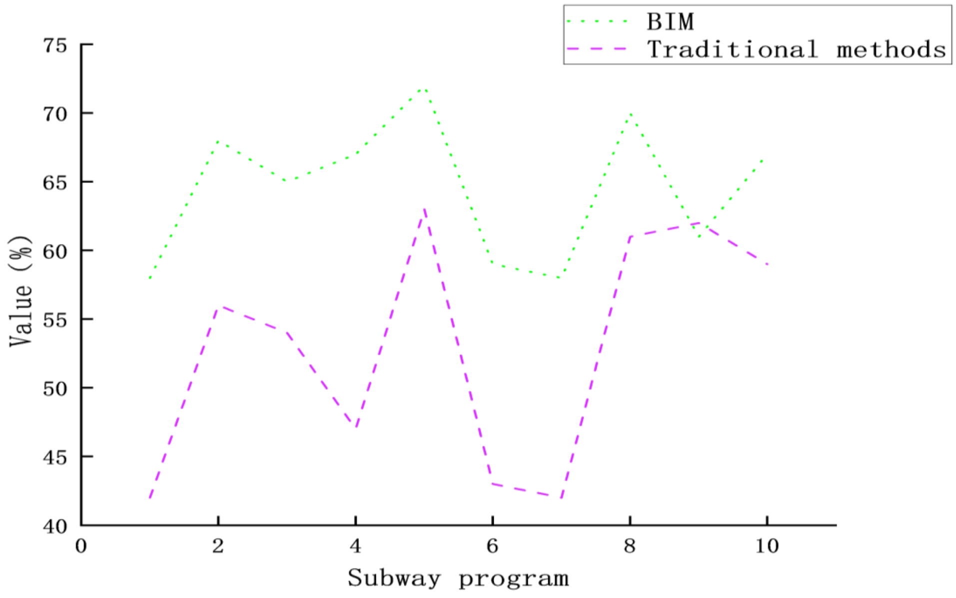

Figure 2: Resource utilization

It can be seen from the data that projects managed using BIM technology generally have higher resource utilization than projects using traditional methods. Specifically, the resource utilization of BIM projects ranges from 58% to 72%, while that of traditional projects ranges from 42% to 63%. The average resource utilization of BIM projects is 64.4%, while the average resource utilization of traditional methods is only 53.3%. This difference reflects the significant advantages of BIM technology in improving the efficiency of resource allocation. When analyzing individual projects specifically, the BIM resource utilization of Metro Project 1 is 58%, while the traditional method is only 42%, saving 16% of resources, indicating the effectiveness of BIM in resource management. The BIM utilization rate of Metro Project 5 is as high as 72%, compared with 63% of traditional methods, showing the potential of BIM in making full use of resources. Projects 2 and 4 also show the advantages of BIM technology, achieving resource utilization rates of 68% and 67% respectively, far exceeding the 56% and 47% of traditional methods. It is worth noting that the BIM resource utilization rate of Metro Project 9 is 61%, slightly higher than the 62% of traditional methods, which may indicate that in some cases, traditional methods can still effectively manage resources, but the overall trend still supports the superiority of BIM technology. BIM can better coordinate the construction process and reduce resource waste through real-time data sharing, collision detection and intelligent scheduling.

4.4 Failure Rate

Finally, the failure rate is tested, and the results are shown in Figure 3:

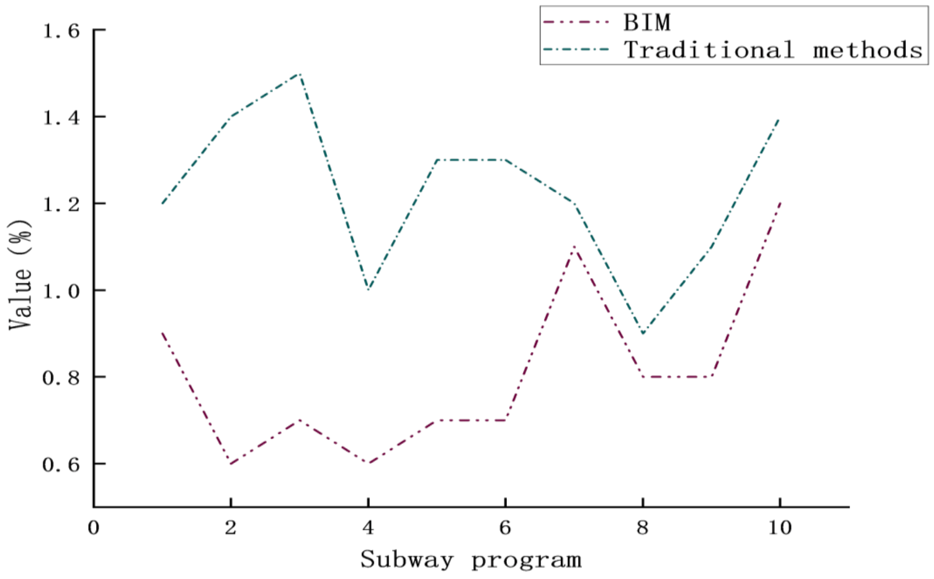

Figure 3: Failure rate

The failure rate of BIM projects ranges from 0.6% to 1.2%, while the failure rate of traditional methods ranges from 1.0% to 1.5%. This trend shows that BIM technology can effectively reduce the probability of failure. Taking Project 2 as an example, the failure rate of BIM is only 0.6%, while the failure rate of traditional methods is as high as 1.4%, showing that BIM effectively reduces the occurrence of potential problems in the design stage. At the same time, the failure rates of Project 4 and Project 5 are 0.6% and 0.7%, respectively, which are significantly lower than the 1.0% and 1.3% of traditional methods. This lower failure rate is mainly due to the visual management and real-time data analysis functions of BIM, which enable problems in design and construction to be identified and corrected at an early stage, reducing the risk of failures caused by design defects and construction errors. In addition, BIM technology reduces the phenomenon of information islands by coordinating collaboration among various disciplines, making work at each stage smoother, thereby further reducing the failure rate.

5. Conclusion

In the full life cycle management of subway projects, the application of building information modeling (BIM) technology has significantly improved the efficiency and management level of the project. By integrating design, construction, and operation and maintenance information, BIM realizes real-time information sharing and collaborative work, optimizes resource allocation, shortens construction cycles, improves resource utilization, and reduces failure rates. These advantages enable the project team to better cope with complex subway construction tasks, improve the scientificity and accuracy of decision-making, and ultimately promote the smooth completion of the project. However, BIM still has some shortcomings in practical applications. The initial investment in data integration and model establishment is high, especially in technical training and software procurement, which may be a burden for some small and medium-sized enterprises. In the future, it is possible to consider combining artificial intelligence and big data analysis with BIM to achieve more intelligent management.

Funding

This work was supported by the Research on the application of BIM in the whole life cycle of Urban Rail Transit (Foundation of Guizhou science and technology cooperation [2019] No. 1420) .The special projects for promoting the development of big data of Guizhou Institute of Technology. And that also funded by Geological Resources and Geological Engineering, Guizhou Provincial Key Disciplines,China(ZDXK[2018]001).

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