Lifecycle Management Method for Urban Road Construction Based on BIM and Digital Twin

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Abstract: With the increase of the scale and complexity of urban road construction, the problems of traditional construction management methods are prominent. This article focuses on the research of lifecycle management method of urban road construction based on BIM (Building Information Model) and DT (Digital Twin). By analyzing the technical principles and application characteristics of BIM and DT, this article constructs a management framework that integrates them, and accordingly puts forward management methods in each stage. In the construction planning stage, BIM is used to build the model and DT is used to simulate the optimization scheme; In the process of construction, real-time monitoring and dynamic management are realized by using them; In the final acceptance stage, BIM is used to integrate data and DT to evaluate the quality; In the operation and maintenance stage, intelligent and refined management is realized based on the two. The research results are expected to solve the disadvantages of traditional management, improve the scientific, refined and intelligent level of urban road construction management, and provide strong support for the high-quality development of urban road construction.

1. Introduction

As the artery of urban development, the construction quality and management efficiency of urban roads directly affect the operation of cities and the lives of residents. With the acceleration of urbanization, the scale and complexity of urban road construction are rising, and the disadvantages of traditional construction management methods are becoming more and more obvious. For example, the poor communication of information among the participants leads to the delay of construction progress; Lack of real-time monitoring in the construction process makes it difficult to detect and solve problems in time; The data in each stage cannot be effectively integrated and shared, which brings difficulties to the subsequent operation and maintenance management [1-2]. Based on this, it is urgent to explore innovative and efficient urban road construction management methods.

BIM technology takes the digital three-dimensional model as the carrier, integrates all kinds of information in the whole lifecycle of buildings, and realizes efficient information sharing and collaborative work [3]. In the field of construction engineering, BIM technology has been widely used in design optimization, construction schedule simulation, cost control and other aspects, with remarkable results [4]. However, urban road engineering has the uniqueness of linear distribution, open-air operation and being greatly influenced by environmental factors. Applying BIM technology to urban road construction management requires adaptive adjustment and expansion according to its characteristics. As a new technology, DT realizes real-time mapping and accurate simulation of the whole lifecycle of physical entities by constructing the virtual digital model of physical entities and relying on real-time data interaction [5]. In manufacturing, aerospace and other fields, DT technology has been successfully used in product design optimization, equipment failure prediction and so on. In urban road construction management, DT technology is expected to reflect the construction status in real time, simulate the construction process in advance, and provide scientific basis for management decision-making.

At present, the application research of BIM and DT technology in urban road construction

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management is still in its infancy. Some studies only focus on a certain stage or a certain link, lacking systematic discussion on lifecycle management [6]; At the same time, the depth and breadth of the integration application of the two are insufficient, and the synergistic effect cannot be fully exerted. In view of this, it is of great significance to study the lifecycle management method of urban road construction based on BIM and DT. The purpose of this study is to integrate the technical advantages of BIM and DT, and build a lifecycle management system for urban road construction. By analyzing their technical principles and application characteristics, this article explores management methods suitable for all stages of urban road construction in order to solve the disadvantages of traditional management methods and improve the scientific, refined and intelligent level of urban road construction management.

2. Management framework of BIM and DT integration

2.1 Integration of ideas and collaborative mechanism

Although BIM and DT technologies have their own emphases, they have the foundation and potential of deep integration. BIM focuses on information integration and visual display, while DT emphasizes real-time mapping and dynamic simulation between physical entities and virtual models [7]. The purpose of integrating them is to use BIM model as data carrier and visualization platform, and to realize the efficient circulation and deep application of urban road construction lifecycle information by using DT's real-time data interaction and simulation analysis capabilities.

The synergistic mechanism of the two is that in the early stage of construction, the design information is integrated and analyzed based on BIM model to provide basic data for DT model; DT optimizes the BIM model by simulating the construction process [8]. During the construction process, the real-time data of the construction site are collected by various sensors, transmitted to the DT model for processing and analysis, and fed back to the BIM model to realize the real-time update of the BIM model.

2.2 Overall management framework construction

Based on the idea and collaborative mechanism of BIM and DT integration, an overall management framework covering planning, construction, acceptance and operation and maintenance stages is constructed, as shown in Figure 1.

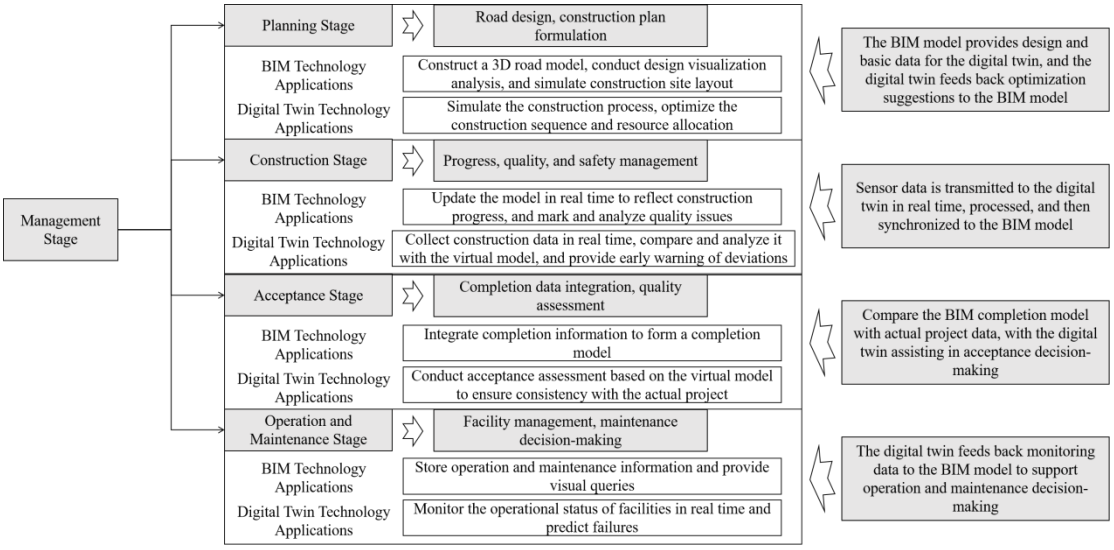

Figure 1 Lifecycle Management Framework of Urban Road Construction

In the planning stage, BIM technology is used to build a detailed three-dimensional model of urban roads, and the linear, cross-section and ancillary facilities of roads are visually designed and analyzed. DT technology optimizes the construction sequence and resource allocation by simulating the construction process under different construction schemes, and feeds back the optimization

results to BIM model to further improve the design scheme. The construction stage is the core link of management [9]. With the help of BIM model, the construction progress information is updated in real time, and the quality problems are marked and tracked. DT collects construction data in real time through various sensors deployed in the construction site, and compares it with the virtual model. Once the deviation between the actual construction and the virtual model is found, an early warning signal will be issued in time to inform the management personnel to take corresponding measures. In the acceptance stage, BIM model integrates all kinds of completion data in the construction process to form a completion model. DT evaluates the acceptance of the actual project based on the virtual model to ensure that the actual project meets the design requirements. In the operation and maintenance stage, BIM model, as the storage and management platform of operation and maintenance information, provides detailed information and visual query of facilities for operation and maintenance personnel. DT monitors the running status of road facilities in real time, such as pavement smoothness and bridge structure health, predicts possible faults, and feeds back the monitoring data to BIM model.

3. Management method of each stage based on fusion technology

3.1 Management method in construction planning stage

In the construction planning stage, the combination of BIM and DT technology can effectively optimize the road design and construction scheme [10]. BIM technology can be used to create an accurate three-dimensional model of urban roads, covering detailed information such as road geometry, underground pipelines and surrounding topography. Through this model, designers can intuitively analyze and adjust the alignment, slope and cross section of the road to ensure that the design scheme meets the engineering requirements and actual terrain conditions. At the same time, DT technology is introduced to simulate different construction schemes. DT model simulates the progress, cost and risk in the construction process according to the design data provided by BIM model, combined with construction technology, resource allocation and other parameters. For example, simulate the influence of different construction sequences on the construction period, and analyze the cost-effectiveness under different combinations of mechanical equipment. Through the comparison of multiple schemes, it provides scientific basis for the optimization of construction scheme. Table 1 shows some simulation analysis results.

Table 1 Comparative Simulation Analysis of Different Schemes at the Construction Planning Stage

Scheme No.	Construction Sequence	Duration (days)	Estimated Cost (10k RMB)	Risk Assessment	Recommendation Index
1	Underground pipeline laying → subgrade construction → pavement pouring	120	800	Medium	★★★
2	Subgrade construction & underground pipeline laying concurrently → pavement pouring	100	850	High	★★
3	Subgrade	110	780	Low	★★★★

	construction → underground pipeline laying → pavement pouring				

Scheme 3 has a good balance in terms of construction period, cost and risk, so it is more recommended. According to the analysis results, the construction team can choose the best construction scheme to improve the scientificity and rationality of construction planning.

3.2 Stage management method of construction process

Management method of completion acceptance stage During the construction process, real-time monitoring and dynamic management are realized through the integration of BIM and DT. On the one hand, BIM model is used as an information integration platform to update the construction progress information in real time. On-site construction personnel upload the actual construction progress to the BIM model through the mobile terminal, so that managers can intuitively understand the completion of each part of the project and find the progress deviation in time. On the other hand, DT technology collects all kinds of data on the construction site in real time, such as temperature, humidity, stress and strain, and compares these data with the virtual model. When the actual data exceeds the preset threshold, the DT model immediately sends out an early warning signal to remind managers of potential quality or safety problems. For example, in the process of bridge pier pouring, if the internal temperature of concrete is too high, cracks may occur. DT model monitors the temperature data in real time, and once the temperature is abnormal, it informs the field personnel to take cooling measures in time.

3.3 Management method of completion acceptance stage

In the stage of completion acceptance, BIM model becomes the core carrier of completion data integration. The design changes, material inspection reports, concealed engineering records and other materials in the construction process are associated with the relevant components of BIM model to form a complete completion model. The model shows the final state of the road and contains rich engineering information. DT technology plays an important role in quality evaluation in completion acceptance. By comparing the actual engineering data with the DT model, the degree of conformity between the engineering entity and the design requirements can be accurately detected. For example, the actual geometric data of road surface is obtained by using three-dimensional laser scanning technology, and compared with the design data in DT model to detect whether the indexes such as road smoothness and road geometric size meet the standards. For the part that does not meet the requirements, DT model can accurately locate and analyze the reasons, assist the acceptance personnel to put forward rectification opinions, and ensure the project quality meets the acceptance standards.

3.4 Management method of operation and maintenance management stage

In the operation and maintenance management stage, the management system based on BIM and DT technology provides strong support for the long-term stable operation of road facilities. BIM model continuously stores and manages basic information, maintenance records and equipment parameters of road facilities. Operation and maintenance personnel can use the visual interface to quickly query the required information and improve the efficiency of operation and maintenance.

DT model monitors the running state of road facilities in real time, and evaluates and predicts the performance of facilities through the data collected by sensors, such as the health status of road structures, traffic flow, aging degree of facilities, etc. For example, according to the stress and strain data of the bridge structure, the safety performance of the bridge in the future can be predicted, and the maintenance plan can be made in advance to avoid unexpected accidents. DT model can also simulate the operation of facilities under different maintenance strategies, provide scientific

reference for operation and maintenance decision-making, and realize the intelligence and refinement of road operation and maintenance management.

4. Conclusions

This article focuses on the lifecycle management method of urban road construction based on BIM and DT. Firstly, the problems existing in traditional urban road construction management such as information communication, real-time monitoring and data integration are pointed out, and the urgency of studying this management method is emphasized. Then, the management framework of BIM and DT integration is constructed, and the integration ideas, coordination mechanism and overall management framework covering planning, construction, acceptance and operation and maintenance stages are expounded. On this basis, the specific management methods of each stage are put forward. In the construction planning stage, the design and construction scheme are optimized by BIM and DT; In the process of construction, real-time monitoring and resource dynamic management are realized; In the final acceptance stage, BIM is used to integrate data and DT to evaluate the quality; Operation and maintenance management stage, to achieve intelligent and refined operation and maintenance.

The integration of BIM and DT technology in the whole lifecycle management of urban road construction can solve the disadvantages of traditional management methods to some extent. Through the implementation of management methods in each stage, information can be efficiently circulated and deeply applied, and the efficiency and quality of construction management can be improved. However, there are still some limitations in this study, such as insufficient discussion on coping strategies under complex geological conditions and extreme climate environment. Future research can further deepen the integration of BIM and DT technology with other emerging technologies and expand their applications in different scenarios.

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