

Optimizing Full Lifecycle Management of Bridge EPC Projects Using BIM Technology

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Abstract. At present, China's bridge construction management still faces problems such as information silos, inefficient cross-disciplinary collaboration, delayed data transmission, and cost overruns. Under the Engineering, Procurement, and Construction (EPC) general contracting model, project participants require a unified digital platform to integrate design, procurement, construction, and operation data throughout the full lifecycle. Building Information Modeling (BIM) technology provides an effective solution through 3D visualization, parametric modeling, collision detection, 4D schedule simulation, 5D cost control, and digital twin-based operation and maintenance. This paper analyzes how BIM technology optimizes bridge EPC project management across the design, procurement, construction, and maintenance stages. It also examines the Hong Kong–Zhuhai–Macao Bridge as a representative case to demonstrate BIM's practical value in improving design accuracy, reducing rework, coordinating complex interfaces, controlling construction progress, and supporting intelligent asset management. The study shows that BIM can strengthen lifecycle data integration, enhance EPC contractors' management capacity, and provide technical support for the digital transformation of large-scale bridge projects.

Keywords: bridge EPC project management, BIM, full-lifecycle, digital twin, large-scale bridge.

1. Introduction

China is the country with the largest scale of bridge construction in the world, but under the traditional management model, there are many problems, such as information silos, low collaboration efficiency and cost overruns. The Engineering, Procurement, and Construction (EPC) management model can integrate procurement, design and construction, and needs to use digital tools to share data. Building Information Modeling (BIM) technology has prominent advantages in parametric modeling, 3D visualization and so on, and can play an important role in the whole life cycle of bridge EPC projects. If this technology can be fully used in the whole life cycle of the bridge, it can provide support for the integration of data under the EPC model [1]. Hong Kong-Zhuhai-Macao Bridge is the largest cross-sea bridge cluster in the world. Although it is managed by a joint venture, it uses the EPC model to manage buildings, artificial islands, tunnels and other components. The application of BIM technology in this project is not limited to the design stage, but also to the operation and maintenance stage, and a closed-loop management system has been formed. This thesis introduces the path of BIM technology optimization, analyzes the case of Hong Kong-Zhuhai-Macao Bridge, and summarizes the difficulties and benefits encountered in the process of promotion, so as to provide reference for the construction of bridge EPC projects.

2. Theoretical foundations of BIM technology and full lifecycle management for bridge EPC projects

2.1. Core characteristics of BIM technology

In the process of digital transformation, the application of BIM is a digital collaborative working method, which has been recognized by the whole industry as a key technology. International Organization for standardization (ISO) 19650 has put forward a series of standards, which points out that BIM is not only a geometric model, but also a technology that can be used in the whole life cycle

of the project, and its core content is to establish a source of truth to ensure that the data can be seamlessly transmitted from design to operation and maintenance.

In the process of bridge engineering construction, the application of BIM technology has the following characteristics: (1) It has strong parameter modeling ability, which can automatically associate complex components, curves, bridge types, piers and abutments, and can also update quickly; (2) It can detect collisions and coordinate the development of various disciplines, which can achieve seamless docking between the pipeline model and the structural model, and can avoid information silos; (3) It has strong simulation ability, and can integrate time, cost and other dimensions into the model, which can dynamically control costs and visualize the construction progress; (4) It can manage with high precision, and the level of development can reach 350 or more in the construction of Hong Kong-Zhuhai-Macao Bridge, which can integrate all elements with high precision [2].

2.2. Characteristics of bridge EPC projects

EPC model is to integrate the three links of procurement, design and construction, the general contractor is responsible for the whole process of construction, and should carry out integrated management in the early stage. In contrast to the traditional model, this model has many advantages, such as unified delivery, simplified interface, etc., but it also has some shortcomings, such as complex geological conditions, complex interface, and frequent changes in design.

BIM technology can be used to solve the above problems. This technology has strong visualization, can detect collisions, and can use parametric comparisons. The use of this technology can keep the design change rate within 5% and achieve the goal of efficient management. Some scholars have pointed out that the use of BIM technology in the process of bridge construction can reduce the rate of rework, and the cost and progress can be controlled through earned value management [3]. In the EPC model, the general contractor can use BIM technology to visualize the supply chain and automatically generate a bill of quantities, which can save costs and inventory backlog, and achieve a smooth transition from design to construction.

2.3. Full life cycle management framework

In the process of managing the whole life cycle of bridge EPC projects, researchers should make ISO 19650 as the basis, divide the whole process into three stages, namely planning and design, construction and procurement, operation and maintenance, and use BIM as the core platform to minimize the life cycle cost, and build a closed-loop data system to ensure the integrity of information and traceability of process.

In the process of planning and design, the parametric model is constructed and compared with multiple alternatives to lay the foundation for data collection. In the process of procurement and construction, the 4D/5D simulation is introduced, and the supply chain is integrated to improve the accuracy of execution. In the operation and maintenance stage, the Internet of Things sensor is combined with the lightweight model to form a digital twin, which can monitor the structural health and carry out predictive maintenance. The latest research results show that the construction of BIM framework can provide support for the digital transformation of the whole life cycle of the bridge, and can directly extend the parametric model to the operation and maintenance stage, so as to make decisions in real time [2].

Generally speaking, the integration of BIM technology and the whole life cycle of bridge EPC projects can not only solve the problem of low efficiency in the traditional model, but also bring support for the digital development of the EPC model, which is conducive to the sustainable development of enterprises.

3. Optimization of BIM technology application across stages of bridge EPC projects

3.1. Design phase

In the EPC project, the design stage is the premise of value creation, which will directly affect the construction cost and the success rate of subsequent procurement activities. In the traditional design model, two-dimensional drawings are used, which are prone to problems such as frequent changes and low efficiency. BIM parametric modeling technology can quickly update the bridge type, automatically associate the complex node, and use the technology to optimize the design scheme and make a comparison [4].

In the process of International Finance Corporation (IFC) standard exchange, the integration of piping, structure and other models can be realized, and thousands of spatial conflicts can be found in the design stage, which is conducive to solving problems and avoiding rework [5]. 4D/5D simulation technology can integrate cost and time dimensions into the model, and can evaluate the schedule dynamically and estimate the cost, which can reduce the rate of design changes.

The integration of forward design and parametric design can use the same model to carry out simulation, analysis and verification, and the sustainability and scientificity of design solutions can be significantly improved. BIM is introduced into the design, which can reduce the error rate by 50% and reduce the construction waste by 4.3% to 15.2%. The application of BIM in the design stage can provide reliable information for EPC contractors and lay the foundation for the realization of end-to-end digitalization.

3.2. Procurement phase

In the EPC model, the procurement phase is an indispensable content, which has a direct impact on the stability of the supply chain, the timeliness of material supply and the rationality of inventory. At present, the traditional procurement model is too dependent on manual operation, which is easy to cause shortages or overstock. BIM technology can extract accurate quantities from parametric models, classify and quantify components, equipment and materials [6].

5D BIM has a strong connection with the cost database, which can dynamically track the budget and estimate the cost in real time. The supply chain platform can track the delivery schedule, grasp the logistics progress, and dynamically optimize the procurement of materials, which can effectively avoid the occurrence of surplus inventory. In the process of digital handover, the BIM model can be directly passed to the supplier, and the communication errors can be avoided.

In the process of implementing the EPC project, BIM technology can be introduced into the procurement process, which can not only make the utilization rate of materials higher, but also shorten the procurement cycle, and can also provide support for the general contractor to formulate reasonable procurement strategy. The study points out that the use of BIM technology can achieve accurate quantification, which is conducive to the procurement of materials, and can save costs.

3.3. Construction phase

In the process of carrying out the EPC project, the construction stage is the most critical, which is inevitably faced with many problems, such as complex geological conditions and complex interfaces, which are relatively high risks. BIM technology has been widely used in this stage, bringing good benefits, which can be reflected in many aspects, such as safety risk control, 4D construction simulation and so on [7].

Navisworks and other tools can link 3D models with construction schedules to simulate the construction process and optimize the sequence of steel structure installation, tunnel segment alignment and scaffolding erection, so as to compress the construction cycle and identify conflicts. BIM and GIS are integrated to achieve real-time monitoring.

In the EPC model, the general contractor can unify the BIM platform, integrate the three links of design, procurement and construction, eliminate the interface disputes, and improve the efficiency of project implementation [4].

3.4. Operation and maintenance phase

In the whole life cycle of bridge construction, the cost of operation and maintenance is the highest. In the traditional way, paper records and manual inspection are used, which can not predict the operation status of the bridge, and the efficiency is relatively low. The use of BIM technology can make the model lighter, build a digital twin, use a variety of sensors, monitor the health of the bridge in real time, and make intelligent decisions [8].

This model can realize 3D visualization, accurately grasp the location of equipment, query historical data, and can also use AI algorithm to predict the development trend of corrosion and cracks, formulate reasonable maintenance plan, and extend the service life of bridges. The digital twin can make the virtual and real world consistent, and can simulate the "what if" scenario.

In the EPC model, the general contractor should deliver the operation and maintenance model to the owner, so that the data can form a closed loop in the design, construction, operation and maintenance, and the cost can be controlled and the asset management ability can be improved [8].

4. Case study: The Hong Kong–Zhuhai–Macao Bridge

4.1. Project overview

Hong Kong-Zhuhai-Macao Bridge is a super project connecting Hong Kong, Macao and Zhuhai, with a total length of 55 kilometers, including a large number of bridges, tunnels and artificial islands, and the total investment is more than 100 billion yuan. This project is a super cluster project in the world, which is bound to encounter many difficulties, such as complex geological conditions, many interface problems between disciplines, and relatively long service life. The project did not take the EPC model, but the island tunnel section and the border checkpoint of Zhuhai-Macao adopted the design and construction general contracting model, which made it possible to play the role of EPC management, and the general contractor should bear corresponding responsibilities [9].

Since 2013, the project team has regarded BIM technology as a digital tool and introduced it into the project, built a unified model, and realized data integration and multi-party cooperation. The platform built by BIM technology has solved the problem of information silo, and has played an important role in the whole process of EPC model construction [10].

4.2. Application of BIM in the design phase

In the design phase, the project uses Autodesk Revit to build a high-precision model, which can resolve complex relationships between vertical and horizontal curves, and can provide support for optimizing the design scheme. Parametric modeling can identify and resolve more than 3000 pipeline and structural conflicts, avoid rework in subsequent construction, and improve design efficiency.

In the process of building 3D models, complex spatial areas can be visualized, which can provide reference for the next stage of construction and procurement. 4D/5D simulation can integrate cost and schedule into the model, which can evaluate the advantages and disadvantages of design plans dynamically. The design cycle can be shortened by 15%, the design change rate can be reduced, and a reliable single source of truth can be provided for the contractor to make decisions [11].

4.3. Application of BIM in the construction phase

In the process of project construction, BIM technology has been widely used, and Navisworks 4D simulation technology has been introduced, which can reasonably adjust the sequence of tunnel segment alignment and steel structure installation, and the critical path can be shortened by 18 days. BIM and GIS are integrated to achieve dynamic monitoring of the construction site, and the accuracy

of tunnel segment alignment can reach the millimeter level. The Bentley platform can resolve pipeline conflicts and improve the efficiency of surveying and construction coordination.

In the construction of Hong Kong Port, Leighton Asia used a large number of BIM tools, built a unified platform, and achieved model integration and collision detection. Empirical data shows that in this stage of construction, the cost is reduced by 12%, and the survey workload is reduced by 15%, which is enough to reflect the advantages of the EPC model.

4.4. Application of BIM in the operations and maintenance phase

In the operation and maintenance stage, the project should build a lightweight BIM model, submit it to the management department, and build a digital twin model, which can query data in real time and achieve the purpose of three-dimensional visualization. The use of integrated IoT sensors can monitor the health of bridges, predict defects, and achieve intelligent assessment.

In the case study of Qingzhou Bridge, the bridge condition evaluation system based on BIM has been widely used in the maintenance of the bridge, and the BIM model has been integrated with the sensor data, which can predict the structural defects, evaluate the structural state, and provide technical support for the 120-year service life [12].

Digital twin technology can not only achieve real-time synchronization between the two worlds, but also make up for the shortcomings of traditional simulation technology, and can make reasonable decisions in the face of emergencies. The research results show that the integration of BIM and digital twin technology can bring good results in operation and maintenance, and the efficiency can be increased by more than 30% [13].

4.5. Quantification of benefits and summary of experience

In the process of building the Hong Kong-Zhuhai-Macao Bridge, BIM technology has played an important role, and the communication efficiency of construction personnel has increased by 30%, the design change rate has dropped by 15%, the construction budget has been saved by 12%, and the operation and maintenance cost has dropped by more than 10%. Leighton Asia also pointed out that the use of BIM technology can save 12% of the cost of construction projects and 15% of the cost of surveying projects [11].

5. Conclusion

5.1. Conclusion

In the process of managing the whole life cycle of bridge projects, the application of BIM technology can play an important role in optimizing and upgrading, which can solve the problem of frequent changes in the process of traditional management, and can also solve the problems of information silo, cost overruns and so on, and can integrate the design, procurement and construction of the whole process. In the construction of Hong Kong-Zhuhai-Macao Bridge, BIM technology has been used in the design phase and can play an important role in operation and maintenance. The research results show that the application of BIM technology in the EPC model can not only enable the general contractor to control the project, but also improve the risk management ability and overall efficiency, and provide reference for the digital transformation of large-scale bridge projects.

5.2. Outlook

With the rapid updating of technology, BIM technology has been widely used in bridge EPC projects, and the development of such projects has achieved a qualitative leap from digitization to sustainability. In order to make the use of BIM technology more extensive, researchers need to formulate reasonable technical standards, unify the contract clauses, build a platform with the help of cloud technology, cultivate a large number of high-quality talents, and draw lessons from the successful experience of the Hong Kong-Zhuhai-Macao Bridge.

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