State-of-the-art of BIM technology and the application in the bridge whole life cycle

Hailong Cao[1, *, †] Tianze Cong[2, †] Xilong He[3, †] Zixiang Yu[4, †]

[1]Shanxi University, Shanxi, 030006, China

[2]Shanghai Normal University, Shanghai, 200000, China

[3]Nanjing Forestry University, Nanjing, 210037, China

[4]Kunming University of Science and Technology, Kunming, 650000, China

[*]Corresponding author: kk2158@wfd.edu.ug

[†]These authors contributed equally.

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Abstract: The progress of science and technology has contributed to the emergence of BIM Technology in construction engineering. However, at present, BIM Technology is mainly developed in housing construction engineering, and very few efforts are paid in the construction of infrastructure, such as bridges. In bridge engineering, there are many participating units and complex processes, whether in the early construction or in the later operation and management, which makes it difficult to apply BIM Technology in the whole process of bridge engineering. In this paper, the application of BIM technology in the bridge design planning, construction, management, and operation were described, respectively. Meanwhile, the application of BIM technology was summarized in the whole life cycle of Bridge projects. In this way, engineers can better apply the BIM technology on bridge engineering, making the project more simple, convenient, and accurate. The visualization and resource sharing etc. of the BIM technology can greatly improve the collaborative ability of work, so that engineers can more intuitively monitor the construction process of every step of the bridge projects, and complete better monitoring.

1. Introduction

The techniques and procedures employed in the field of Architecture, Engineering, Construction, and Operation (AECO) are developing at a quick pace, yet with that progress comes new expectations that appear to be expanding even faster. Massive infrastructure projects are becoming more and more prevalent as the world economy grows stronger. As a result, linked organizations must develop new technologies to generate plans and documents, as well as to manage the ever-changing construction process. Drawing software (such as AutoCAD) is now available that allows plans to be designed and amended as needed. However, this technology has since been phased out in favor of Building Information Modeling (BIM), which is more efficient in terms of data integration and delivers a better user experience. Nederveen et al. [1]. proposed the following definition of BIM: “A model of information about a building that comprises complete and sufficient information to support all life-cycle processes and which can be interpreted directly by computer applications. It comprises information about the building itself as well as its components, and comprises information about properties such as function, shape, material and processes for the building life cycle.”

BIM-related technologies, which are rapidly being used in building construction, are gradually being adopted for infrastructure projects such as bridge construction. While BIM technologies are among the most advanced in terms of modeling simple to complicated structural elements, they are nevertheless limited in terms of successfully completing a bridge project. If we can get a consistent BIM model throughout the design, construction, operation, and maintenance phases of a project, the efficiency of the project will significantly improve. Additionally, despite some major advancements in recent years, the Industry Foundation Classes (IFC) data system remains limited in terms of infrastructure initiatives. Several studies examined methods for extending the functionality and intelligence of objects, or for associating objects with innovative design methods such as 4D CAD [2], while others focused on more precise subjects in order to extend the IFC standard, such as creating cross sections for road design or extensions for road structures and digital modelling [3-4]. However, in the realm of civil engineering structures, more specifically bridges, such models have not yet achieved complete success.

BIM is a 3D digital technology which can integrate many kinds of operation information of construction engineering digitally. It can also integrate kinds of in formational digital technology in many kinds of work in construction engineering, and combine various of information in construction engineering. The use of BIM by designers and contractors in construction projects can make correct solutions to the problems encountered in the project and strengthen the collaborative operation mode of the project. Building information is also a means of applying information technology in design, construction, and management, which can significantly improve the efficiency and greatly reduce the risk of construction projects throughout their life cycle. Thus, there is still a need for a tool capable of manipulating bridge elements along curved paths, while also allowing the user to freely modify the model and apply it to a variety of different structures, including the associated parameters.

The purpose of this paper is to help more engineers understand BIM models and better utilize the benefits of BIM technology in engineering. Firstly, the advantages of BIM technology in the engineering design, construction, operation, and maintenance management processes are discussed, respectively. The unified parametric model may be integrated with particular geographic information to provide a more comprehensive picture. So that engineers do not have to start from scratch and rebuild the whole thing from scratch, and will be able to significantly enhance work productivity while also shortening project timelines. The project's lifetime might range from a few months to many years; therefore, it is critical that the quality of the work be improved. As a result, the central theme of this paper is the integration of BIM Technology across the whole project life cycle in order to successfully finish it. In addition, whether there will be a more optimized and unified program for software programming of BIM technology in each branch is also a problem. The purpose of this paper is to summarize the application of BIM technology in various stages of bridge construction, and to present the role and influence on the whole life cycle of the bridge.

2. Application of BIM technology in the bridge whole life cycle

2.1 Application of BIM technology in bridge design

2.1.1 Feasibility analysis

Feasibility analysis is critical during the design stage of a bridge engineering project because it determines whether the entire bridge engineering project meets construction requirements and can comprehensively analyze any potential problems that may exist in order to provide reliable support for the construction of subsequent bridge engineering projects. BIM technology is quite useful at the feasibility analysis stage of a bridge dyeing project. It can conduct a full feasibility study of bridge engineering projects based on a thorough and extensive analysis of different essential facts and information, ensuring that subsequent planning and design work is more purposeful. By utilizing BIM technology, daily planning and design personnel for bridge engineering projects can easily import the corresponding BIM platform based on the large amount of data and information obtained, thereby promoting accurate analysis and evaluation of these data and information, forecasting the possible bridge structure system, and considering the application effect of various bridge structure schemes. Adjust proposals that are absolutely unfeasible for the opponent in order to guarantee that the future construction is inexpensive and acceptable and to prevent major limits and repercussions created by unrealistic expectations.

2.1.2 BIM-based parametric modeling in design phase

According to Woodbury [5], parametric modeling is considered a "propagation" system, a system of elements that are linked together through relationships and that evolve together, one after the other. This system can therefore be seen as a series of mathematical equations made up of variables which, when fixed, give rise to project proposals. De Boissieu [6] provides a very similar definition by stating that "a parametric model is constructed from a set of elements related to a system of dependencies".

This approach for spatially representing structures is constantly expanding in the industry of construction, with designers increasingly aiming to save time by utilizing parametric models. Traditional design software, such as CAD, requires multiple steps to input parameters and analyze data. However, BIM technology can accomplish these processes simultaneously (as shown in Figure 1). For example, by using the parametric modeling program Revit, we can easily modify the kind of beam bridge by simply changing the input parameters such as the plan Section, the number of piers, and the length of each bridge abutment. All items in are organized into families, which enables designers to handle data and make changes quickly. Each family can describe several kinds, and each type can be constructed in a variety of sizes and forms, with the addition of parameters to enable parametric design. Due to the complexity of bridge engineering components, employing families to construct bridge components enables comprehensive fine modeling, and by inserting families, the difficulty of modeling big and complicated bridges in a single operation window is decreased.

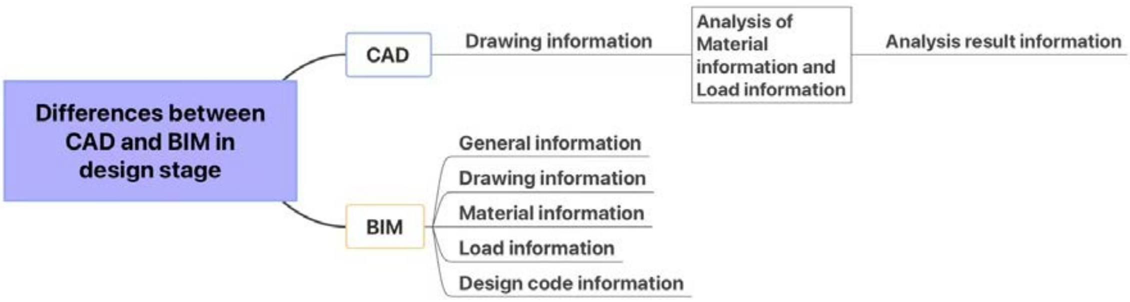

Figure 1. The differences between CAD and BIM in design stage.

2.1.3 Visualization of BIM Technology

BIM visualization technology allows the geometric appearance of a BIM model to be displayed without losing geometric and geographical data, and the geometric appearance of bridge structure can be browsed from different angles by using basic functions such as translation and rotation, allowing the owner to understand the overall picture and detailed requirements of the building at an early stage in the project's development cycle. Construction staff can use it to query and master construction information, which can then be used to guide construction at the same time. Two-dimensional drawings of the bridge's structure are inadequate, and several drawings must be spliced together in order to track the progress of the construction. The progress of the construction cannot be monitored in real time. Using the visual cloud platform, the design progress and construction time can be linked together, and the on-site concrete pouring information, concrete construction information, and reinforcement construction information can be linked together with the platform model, allowing for the creation of statistics on the actual quantities consumed and construction conditions on site, allowing management personnel to master the on-site pouring mode and washing time as well as the quantities consumed and construction conditions on site. Construction progress should be adjusted, and construction costs should be controlled, in accordance with the construction time and quantities.

2.1.4 The calculation of structure

Structural design based on BIM technology can be solid detail representation of steel bars, steel bars 3D visualization, intuitive presentation in the plane section view; It can be connected with the structural design software, and the accurate steel size and positioning technology can directly guide the construction; It can proofread the complex reinforcement joints and calculate the reinforcement directly. For example, if you have a bridge where you need to calculate the amount, thickness, and shape of the steel bar you inserted into your design. BIM will automatically calculate the amount, size, and shape of the steel bar you need, compared with the traditional hand-drawn drawing and 2D drawing software such as CAD, it is more three-dimensional and accurate display of the bridge components, but also more convenient for related calculations.

In Bridge Construction, not only reinforced materials, but also concrete, cement, steel and many other materials. Because of the different structure of the bridge, it is difficult to calculate the amount of material accurately by the conventional algorithm. In BIM, list all the information that needs to be calculated, calculate it using functions, and export the data. This greatly reduces the calculation of the workload, but also reduce the possibility of error, but also improve efficiency. The computer calculation replaces the traditional manual calculation, which reduces the error rate and ensures the validity of the data.

2.1.5 BIM technology in design checking

In the aspect of bridge design check, first of all, according to the bridge 3D modeling, check the necessary composition structure is complete. In addition, it is necessary to check the stability of the bridge, such as load check, strength check, stability check, etc. In the traditional checking model, the checking calculation is carried out by using various empirical formulas and formulas stipulated in the specifications. But with BIM, you can do the calculations directly with programming software and see the results when the modeling is complete. This greatly saves time and improves accuracy.

More detailed aspects, such as Pier anti-overturning calculation, road load design and so on. All of these operations can be calculated by programming software and integrated together. Staff do not have to do the calculations themselves, but only need to check the exported data.

2.2 Application of BIM technology in bridge construction

BIM technology provides 3D visualization, management of material and information and 4D construction simulation in the whole construction [7]. Because bridge projects are usually massive and involve many specialties, the application reduces substantially construction difficulty. Therefore, it helps to enhance efficiency of construction, quality of structure and construction safety.

2.2.1. Visual 3D model in construction

Building 3D model based on BIM technology can realize visual representation in the construction. Comparing with conventional 2D drawing, it can show the all-wave bridge intuitively and location of members. When revising the model, just modify one data can update the whole model automatically. It plays an auxiliary role in the construction.

BIM technology can assistant the engineering drawing joint check-up and technical clarification. It can analyze and calculate automatically engineering quantity based on the 3D model. Comparing with artificial statistics of numbers and calculation, using the technology is faster and more accurate. For the bridges that involves abundant members, using it can reduce manpower, accelerate progress and eliminate error by regulators. And it is earlier to discover the mistakes and revise. In the technical clarification, most projects adopt the traditional mode of “writings+2D drawings”. Yet, field operations are becoming more complex and builders understand them harder. 3D visual representation can help to understand to save time. For example, combining 3D-printing and Augmented Reality (AR),technology can use tiny members and even the whole bridge to simulate the operations, as shown in Figure 2 [8]. Hence, using the technology can increase efficiency of engineering drawing joint check-up and technical clarification.

3D model can be applied in manufacture and erection of prefabrication members. Prefabrication members have many advantages, for instance, saving the time, environmental protection, which are used more and more. Manufacturing them according to the traditional 2D drawings, some problems of spatial positioning often arise to cause erection more difficult. Using BIM technology can manufacture prefabricated members based on 3D model to ensure accuracy. For the process of erection, BIM can also provide center of gravity of members and coordinate of lifting points accurately, which is convenient to erect quickly.

Figure 2. 3D printed bridge [8].

2.2.2 Elaborating management of material

BIM provides a forum where an organization log some data and other co-operative organizations can find them accurately. Using the forum can get clear data and strengthen cooperation to enhance efficiency of construction and reduce costs. For large and complex project of bridges, the cost of materials occupies 60%~70% of the total cost and material management needs multiple construction organizations and units to work together. Therefore, elaborating management of material is important. Timeliness and accuracy of BIM technology affect effectively in elaborating material management.

The elaborating management model based on BIM contains three aspects, which are material procurement, material warehousing and on-site consumption [9]. The function of calculating engineering quantity can help to draw up purchase plan and the BIM forum can realize more smooth communication with suppliers. It improves efficiency and reduces costs of procurement. It also can clarify the status of the materials. Hence, it helps to ameliorate the situation of lack of standardization in material storage and save the materials and costs. Besides, on-site consumption can be recorded clearly in the forum. It can reduce the waste and improve recycling rates. In the case of southern anchorage of Yidu Yangtze River Bridge, using the BIM technology in material management kept the attrition rate of steel within 1.5%, reducing about 1% comparing with traditional mode [9].

The system combining with the Internet of Things can also achieve material sorting, precise positioning and visual management. Logging the information into the system can generate BIM bar code labels. Then when inputting the name of project, a series of information can be available including the specification, manufacturer, status, location, etc. It can save the time and manpower of seeking materials.

2.2.3 4D construction simulation

BIM technology can simulate the whole construction progress, based on the 3D model adding the time dimension. The technology help to optimize construction plan, understand the process of construction fast, find and solve problems in advance. And actual construction process can also compare with it to analyse and adjust plan timely. So, 4D construction simulation can improve efficiency of construction, save manpower and material resources resource and ensure the safety.

Simulation before starting construction impacts on the quality and speed of construction. For overall process, the simulation can show relevance between some process operations, whether the division of the construction segment is reasonable, whether the arrangement of sequence is feasible, etc. [10]. Ensuring their practicability is the key to guarantee the smooth construction. For one unit of process, especially precise and complex ones, using BIM can make simulation and decomposition of construction technology, as showed in Figure 3 [11]. By simulating time and time again, BIM can help to optimize construction plans, exclude members collisions, select the appropriate construction machinery and technology. Besides, builders can understand construction flow better to remedy lack of professional knowledge by watching vivid simulating. It can help builders to decrease errors in construction, improve efficiency and reduce risks. And BIM technology can visualize, simulate and even quantify the risks [12]. Finally, river or road closed can be informed to public as early as possible to reduce losses. Therefore, it can realize the management and control of every detail to eliminate safety risks in the actual construction and avoid the losses of time and economic caused them.

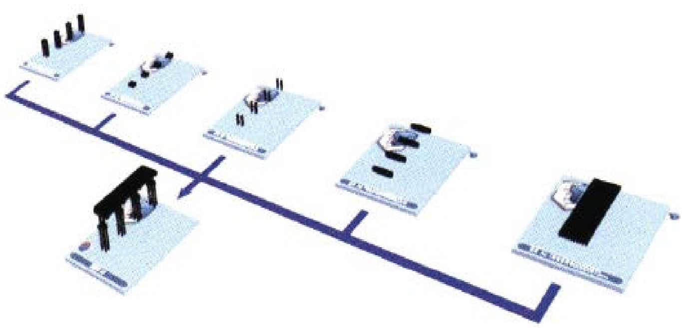

Figure 3. Decomposition of construction technology [11].

During the construction, predicting trend of proceeding is also good method of improving efficiency. BIM can establish 4D schedule model based on the actual construction proceeding. Because of difference between simulation and reality, the model is dynamic. Therefore, recording changes, surveying actual situation and connecting with the mathematical mode can predict subsequent working period and the development trend of the process. The deviation range of the proceeding can be analyzed and the project management personnel also can do the dynamic adjustment in time according to the deviation [11]. With studies of mathematical mode, accuracy of prediction will be more and more. Hence, using BIM technology can improve the efficiency of construction increasingly.

2.3. Application of BIM technology in management and maintenance

At each stage of a construction project, massive volumes of data and information are generated. For the effective delivery of the constructed item and its end-use, detailed design information is created. Data is also generated throughout the life of the structure until it is demolished [13]. People now focus on how to achieve subsequent operation and maintenance of the bridge using a big amount of data. With the fast development of the Internet, Internet of Things, big data, and other technologies, the introduction of BIM technology gives a new method for operating and inspecting bridge. BIM technology is based on building models and relies on building data as its foundation. To accomplish the integration of bridge construction and maintenance, as well as the digitized and intelligent management and maintenance of the whole life cycle, big data analysis and intelligent monitoring technologies are being used [14].

2.3.1 The key technology of BIM intelligent management platform

(1) BIM+ asset maintenance management

The integrated application of BIM and the asset maintenance management. Through the bridge physical and digitalization of assets and virtualization, the sensors will import the real-time wind load, temperature, humidity, earthquake load, and real-time traffic situation in order to realize the visual management and application of bridge model in virtual space [15]. Simultaneously, the BIM data platform can store historical inspection, maintenance and repairing data. Through big data comparison, summarizes the damage resistance, damage rule and the way the parts repair of important components of bridge, reduce the total life cycle cost and avoid the occurrence of major accidents.

(2) BIM+ Internet of Things

The integrated application of BIM and the is fundamentally the integration and fusion of information throughout the construction process. At the top level, BIM technology is responsible for information integration, interaction, display and management, while the bottom level, the Internet of Things is responsible for information perception, collection, transmission and monitoring. It can simultaneously and continuously identify, collect, monitor, and manipulate the information of content of bridge operation conditions and natural environment changes in real by relying on Internet of Things video front-end development, positioning equipment, sensing technology and other equipment. According to the characteristics of mobile Internet, the main parameters of mobile Internet are summarized as database management to generate continuous and traceable dynamic detection records. These records and key parameters aid in the updating of the 'static data BIM entity model' real-time data information. Through the effective connection of human, object and BIM entity models, various independent and dispersed data information can be displayed in the ‘3D virtual reality technology entity model’ of engineering buildings.

(3) BIM+ cloud computing

The integrated application of BIM and cloud computing is to convert BIM applications into BIM cloud services by leveraging cloud computing benefits. Large and complex work in BIM applications can be transferred to the cloud to improve computing efficiency, thanks to the cloud's powerful computing capacity. The cloud computing-based large-scale data storage capability can synchronize BIM models and related business data to the cloud, making it easy for users to access and share with collaborators at any time and from any location.

(4) BIM+ virtual reality technology

The integrated application of BIM and virtual reality technology can improve the authenticity of simulation. Any relevant information can be integrated into the established virtual scene for joint simulation of multidimensional model information. It can view the relationship between various information and model in real time and from any Angle guiding monitoring personnel to carry out relevant work.

2.3.2. Function of BIM technology in bridge management and maintenance

Real-time data update and correction functions are realized based on the BIM model, so that bridge information can be effectively organized and tracked during management and maintenance. Also, BIM database can be created to store a variety of data during the bridge's operation process and support the creation and updating of dynamic information during the project's operation to ensure data compliance and integrity. In addition, the creation of BIM visualization platform, which can create a three-dimensional model and the display and query relevant data information. Besides, the BIM model is combined with the bridge management system to create an integrated, convenient and intuitive intelligent maintenance management technology for BIM-based long-span bridges.

2.3.3. The project using BIM intelligent management platform

(1) Brief Introduction of Project

There is a project of BIM-based engineering. The gold and silver lake surrounded by the road which is about 9.42 km in Wuhan. To master the bridge health status any time and ensure the safety of the bridge operation, BIM intelligent management platform has been established for Nijiang River Bridge and Jinghe Bridge on lake-ring Road. In this project, the bridge body structure is complex, especially Nijiang River Bridge, which adopts inverted trapezoidal section of the main arch and the auxiliary arch to form a complex V-shaped spatial curve, and it increases the difficulty of structural safety monitoring in the operation and maintenance process.

(2) The application situation

The BIM technology is used to associate the sensor with the BIM model, and the data is transmitted to the BIM intelligent management platform to realize the visual operation and maintenance management scheme for safety monitoring. Based on the monitoring data of BIM model, whether the real-time monitoring data is in a reasonable range. When the monitoring data exceed the set threshold, the system can automatically send a warning signal and notify relevant personnel, and describe in detail the warning location, monitoring value, possible situation and possible solution. The BIM model is connected to the database of daily inspection and maintenance of lake-ring Road, and the daily maintenance information such as text, pictures and video is uploaded remotely and in real time. All departments work together efficiently on the platform to achieve a paperless, informatization and refined maintenance process closed-loop.

3. Conclusion

BIM technology has shown great advantages in visualization, integration, parameterization and optimization. This paper focuses on the integration framework of BIM technology in the whole life cycle of bridge engineering, as well as the technical application and performance of BIM in each important stage of the whole life cycle of bridge. The application of BIM is also discussed in the design stage, including feasibility analysis, parametric design, Visual 3D Model, Unified Management and 4D Construction Simulation for the construction phase. Then the BIM intelligent management and maintenance platform and its technical support in the operation and maintenance stage are investigated and studied. However, comparing with housing construction engineering, the application of BIM technology in bridge engineering is still not comprehensive in-depth. Meanwhile, due to the wide variety of BIM modeling software and the lack of relatively clear core software, it is not conducive to the application and promotion of BIM technology. In addition, the imperfection of BIM technology also restricts the application and development of BIM technology in bridge engineering to a certain extent. The application of BIM technology in the field of bridge engineering is a systematic and overall work which needs to be guided vigorously from the aspects of rules and regulations at the national and industrial levels to gradually improve the BIM technology system. The technology is massive technological change of bridge engineering and provide guarantee for the bridge whole life cycle. As a whole, BIM technology can facilitate communication, which is reflected in visualization of engineering drawing joint check-up and technical clarification, integration of information at each stage of the bridge whole life cycle, integrated maintenance system and so on. The application help to solve the problems of missing information and difficulty of sharing in different stages of design, construction and maintenance and improve the efficiency of collaborative work. Besides, it also has great effect of every stage individually. In the design, feasibility analysis is more comprehensive, parameterization can save the time and visualization can reduce errors caused by regulators. Then, for construction, using intuitive analysis for 3D model can improve the quality of construction, elaborating material management reduces the costs effectively and 4D construction simulation can eliminate risks and shorten the construction period. It also creates an intelligent maintenance management system to real-time monitor kinds of date and ensure the normal operation of the bridge. Therefore, from planning to construction, maintaining to demolishing can use BIM technology widely to improve the efficiency. It also accords with the requirement of green development. BIM technology will become a consequent trend in the bridge engineering for the sake of the above obvious advantages. Meanwhile, it has a large practical significance to promote intelligent and green development of the engineering.

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