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Research Article

Monitoring and Maintenance of Highway Super-Large Bridge Based on BIM Technology

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As the key node of highway traffic in China, the super-large bridge is the most important infrastructure of the country. With the completion of large-scale infrastructure construction in China, the key work of super-large bridges has changed from construction to maintenance. The service life of the super-large bridge is long, and with the increase of the service life of the super-large bridge, the annual maintenance cost is also increasing. At present, with the rapid development of super-large bridges in China, the diseases of super-large bridges are also increasing, and the maintenance and management of super-large bridges have become an urgent problem to be solved. In order to solve this problem, this paper takes the highway bridge as the research object and, on the basis of mastering the actual needs of the maintenance management of highway bridges in China, puts forward the monitoring and maintenance of bridges based on BIM technology, solves the lack of maintenance information elements in traditional BIM technology, studies the establishment method of the maintenance information model, finally develops the basic data acquisition software of the BIM model, accurately locates the disease position of the highway bridge, realizes the three-dimensional visual information management system of bridge, and continuously improves the maintenance efficiency. The research results show that starting from the monitoring and maintenance information management of highway bridges, the BIM data management method of the highway bridge maintenance stage is put forward, which realizes the visual management of maintenance information of highway bridges. Based on the analysis of the hierarchical information model of bridges, the component coding system of a bridge facing the maintenance management stage is established, and the visual management of diseases of bridges is put forward. Using BIM technology to assist the evaluation method of super-large bridges, using relational database and VBA project manager, based on the theoretical algorithm and interface design, automatic maintenance decision-making suggestions are realized. BIM technology is proposed to assist maintenance inspection and evaluation decision-making, and automatic and visual maintenance management of super-large bridges is realized. The research results provide practical guiding significance for further realizing the maintenance management system of highway bridges based on BIM technology.

1. Preface

With the rapid development of China's highway construction, the extra-large bridges in the highway are developing in the direction of long-span, new materials, and high quality, and new-type extra-large bridges have brought great convenience to China's transportation [1, 2]. With the continuous increase of extra-large bridges, the number of dangerous bridges and sick bridges is increasing every year. According to the statistical survey data, 42% of the super-large bridges in China's highways have been in service for more than 20 years, of which 32% have suffered from third- and fourth-grade diseases, and more than 100,000 have been identified as dangerous bridges [3–5]. For example, the Hong Kong-Zhuhai-Macao Bridge, as the lifeline of China's economy, will directly cause huge personal and property losses once accidents such as collapse occur. According to the statistics in Table 1, the bridge accidents in China in recent ten years have caused serious casualties and heavy losses of property.

Table 1: Domestic bridge accidents in recent ten years.

Date	Name of accident bridge	Stage	Accident cause	Casualties
2014.8.8	Shanxi Guangchang Hedong bridge	Run	Improper maintenance	Two dead and two wounded
2016.7.9	Guizhou Jiangyou Panjiang bridge	Run	Insufficient maintenance and reinforcement	Five dead and seven missing
2018.11.19	Ya'an Jinshan bridge	Build	Irregular construction	1 dead and 10 wounded
2019.9.11	Ganjiang highway bridge	Demolish	Demolition risk	3 lost contact and 5 injuries

With the rapid expansion of national highway construction and operation scale, the maintenance of super-large bridges has also entered a rapid development stage, and a large number of new technologies have been applied to the monitoring and maintenance of bridges [6]. Use of advanced Internet information technology, blockchain, big data, artificial intelligence, and other new technologies has become a systematic and modeled development trend of bridge monitoring and maintenance [7]. Traditional bridges will generate a lot of information from the beginning to the end, including design drawings, construction, and operation information, but the information will not be transmitted, shared, and utilized during the project execution. Usually, the design results produced by the design unit are handed over to the construction unit with drawings [8]. According to the drawing information, the construction unit uses the cost software and the project schedule management software to establish the implementation schedule, and after the construction, the completed drawings will be delivered to the owner [9]. The owner establishes the operation and maintenance model according to the as-built drawings and inputs the data into the integrated management platform of operation and maintenance, so as to realize the later operation and maintenance management of the super-large bridge [10]. On the whole, in the whole life cycle of the bridge, each data information is kept in the main participating units in each stage in isolation, and the information achievements in different stages cannot be reused, which easily leads to waste of resources and increases the probability of errors [11].

The visualization and integration characteristics of BIM technology provide a new solution for the maintenance of highway extra-large bridges. Some researchers build the BIM platform to manage the operation and maintenance of the bridge, which mainly reduces the cost of visualization, improves the ability of data integration and expression, and realizes the data interaction and statistical functions [12]. At present, BIM technology has carried out some research on super-large bridges in the maintenance of bridges. Some researchers put forward a three-dimensional visualization display of bridge health status based on BIM technology and established a lightweight visualization model of the bridge through Dynamo [13, 14]. Combined with the dynamic correlation between the monitoring data collected by bridge sensors and the BIM model, the three-dimensional visualization of the bridge maintenance model was realized, and the function of viewing monitoring data and automatic alarm was continuously improved [15–17]. By analyzing the monitoring data of the bridge, some researchers put forward the design scheme of the bridge health monitoring system based on BIM technology and established the bridge health monitoring and maintenance management platform through practical projects [18]. Some researchers proposed the BIM technology design of the 3d visualization model of bridge diseases, which solves the matching problem of bridge disease body properties, such as dimension, using WebGL technology development of 3d visualization software online; the bridge disease has realized 3d visualization displaying bridge structure cracks and local disease and disease history evolution of bridge disasters. In order to solve the current problems of scattered distribution of bridge diseases and lack of global judgment, some researchers carried out the distribution of bridge diseases through BIM technology and developed a three-dimensional visual bridge disease information collection, visualization, and analysis system.

BIM technology, as a booster of informatization reform of highway construction in China, has the characteristics of visualization, refinement, and collaboration, which greatly reduces the construction cost, improves the informatization level, and promotes the development of green buildings in China [19, 20]. With the continuous application and promotion of BIM technology, it is necessary to solve the maintenance problem of highway extra-large bridges. Taking the highway bridge as the research object, this paper establishes the monitoring and maintenance of bridges based on BIM technology, solves the lack of maintenance information elements in traditional BIM technology, develops the basic data acquisition software of the BIM model, accurately locates the disease position of highway bridges, and realizes the three-dimensional visual information management system of bridges, thus providing practical value for establishing the maintenance and management system of BIM highway bridges [21, 22].

2. Application of BIM Technology in Maintenance of Super-Large Bridges

The maintenance contents of the extra-large bridge mainly include inspection, evaluation, maintenance, reinforcement, etc. In this paper, BIM technology is applied to the maintenance of super-large bridges. According to the information elements required for the maintenance of super-large bridges, an information model for the maintenance of super-large bridges based on BIM technology is established, so that the information of design, construction, inspection, maintenance, reinforcement, and other projects can be effectively linked in the whole life cycle.

2.1. Data Collection and Information Collation. In order to establish the maintenance model of the super-large bridge, the data collection scheme should be established first, and the technical data of the super-large bridge should be collected, including design planning, geological survey, construction records, completion reports, inspection data, maintenance records, etc. After collecting the information of the super-large bridge, sort out and analyze the useful information in all the information; obtain the information of the route number, bridge site, load, and geological conditions of the super-large bridge from the planning and geological prospecting data; obtain the geometric information of the components of the super-large bridge from the construction drawings; obtain the construction process information such as the construction date, responsible parties of subprojects, and material grades from the construction records; and obtain the operation and maintenance information of the super-large bridge from the completion data, inspection reports, and maintenance records.

As a key work in the maintenance of super-large bridges, the disease information of the super-large bridge is standardized and discretized to collect and display the disease information of the bridge when the maintenance information model is established. According to the association of bridge disease information, the relationship between the content of the designed data table and each data table is established, and the maintenance information database of the super-large bridge realized by the BIM model is established on the database server.

2.2. Establishment of Maintenance Information Model of Super-Large Bridge Based on BIM Technology. The information involved in the maintenance stage of the super-large bridge is more extensive, mainly including drawings, construction records, inspection reports, disease records, photo data, etc. When BIM technology is adopted for integration, it is necessary to extract the description objects of the model and establish the relationship between objects and the information points contained in each object according to the technical characteristics. For the maintenance of super-large bridges, it can be divided into the whole, parts, components, diseases, maintenance, and reinforcement measures of super-large bridges, among which the whole, parts, components, and components can be derived from each child object. The object relationship is shown in Figure 1, and the arrow points to the parent object.

This paper mainly studies the disease object and describes that the disease attribute of the bridge is related to the component object and maintenance measures such as crack filling and repair. Each object contains information of levels/things. The whole object of the super-large bridge contains information such as the name, line, coordinates, and load grade. The part and component objects contain information such as members, inspection, and evaluation, and the component objects contain information such as component geometry information, construction time, and disease. The disease objects contain information such as disease type, degree, discovery time, and repair.

After determining the component division, determine the fineness of modeling. For the maintenance of extra-large bridges, BIM models are mainly established for the purpose of maintenance, which should reflect the shape, mechanical characteristics, disease distribution, and maintenance scheme of components. At the same time, when the model is too fine, the workload of modeling is greatly increased, which is not conducive to the performance of the 3d display system. How to determine the way and details of component splitting has become the key of BIM modeling.

2.3. BIM Model Component Division of Super-Large Bridge Maintenance. The BIM model is different from the general three-dimensional model, which not only contains the three-dimensional geometric model of the super-large bridge but also contains the corresponding information. BIM model building needs to split the components according to the super-large bridge. Too many components are split too thin, which will be occupied by a lot of low-value details, increasing the cost of useful information maintenance and system operation. When the components are split too thick, it will also lead to the loss of key information, which limits the operation analysis work. The split method of components is closely related to the acquired information. The split component is the smallest unit of information description, and its construction, damage, maintenance, and other information are recorded in detail. As the basis of carrying information, the rationality of building split directly affects the utilization efficiency of information. In the BIM model, the geometry of components is bound to the database component ID and linked to the component information in the database.

2.4. BIM Technical Advantages. The visualization and integration characteristics of BIM technology provide a new solution for the maintenance of super-large bridges. The BIM platform is used for the operation, maintenance, and management of super-large bridges, mainly including the following:

2.4.1. Reduce the Cost of Visualization. Through Revit software, object-oriented and parameterization are combined, data and models are combined, and at the same time, it has powerful graphics processing capability and open API library, which facilitates secondary development and effectively saves the cost of visualization.

2.4.2. Enhance the Ability of Data Integration and Expression. BIM software has strong management ability for models, and the data are stored in the model in the form of model parameters. These model parameters can be updated and queried in real time and can be related to each other in different models. When the data in a certain place is modified, all model data will be updated to ensure the data consistency. Therefore, in the maintenance stage of the super-large bridge, according to the BIM model in the construction stage, by adding the data parameters of the maintenance module, all the data can be linked to the components, and the data can be queried accurately.

2.4.3. Realize Data Interaction and Statistical Functions. Based on the BIM platform's ability to manage components, the statistics of data can be completed. Through the

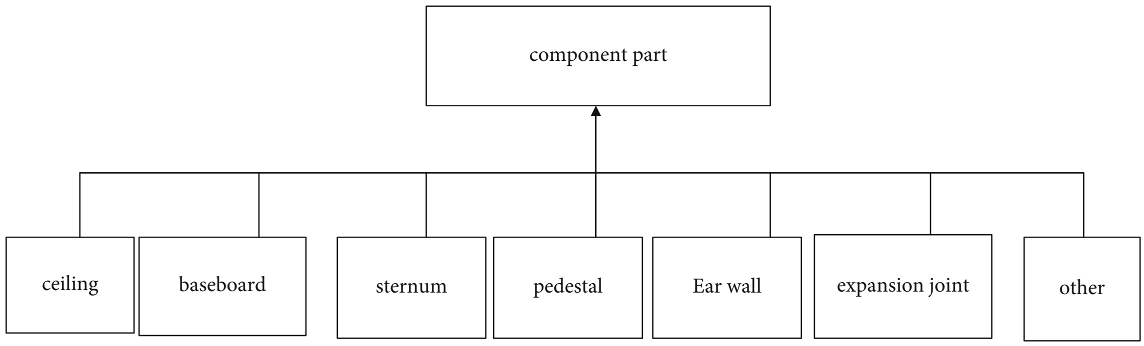

Figure 1: Division of component objects in maintenance model of super-large bridge.

powerful API, the operation and maintenance management system interacts with BIM software, and the data is sorted and calculated by operating the model components, and then, the calculation results are returned, thus avoiding mistakes in the manual statistics process and realizing efficient management.

3. Realization of Monitoring and Maintenance of Highway Super-Large Bridge Based on BIM Technology

In the whole life cycle management of the super-large bridge project, the operation and maintenance is the longest, and it also involves the largest amount of information and management workload, with the cost accounting for 65%~70% of the total project cost. At present, a large part of the existing highway bridges in China was built in the middle and late last century. These bridges have been in service for many years. However, most of the newly added bridges in China are in the peak period of highway construction, and most of them have the problems of short construction period and hidden construction. At the same time, with the rapid growth of traffic volume and the continuous improvement of transportation and carrying capacity in China, these bridges deteriorate rapidly. The operation, maintenance, and safety performance of super-large bridges have become the most important issues.

At present, China has formulated the maintenance standards of super-large bridges, which mainly include facility inspection, safe use inspection, reinforcement and maintenance of components, and improvement of technical files. Therefore, the maintenance of the extra-large bridge includes manual and electronic inspection, safety status management, decision-making, and establishment of data files. The main process is shown in Figure 2.

3.1. Implementation of Manual Inspection Based on BIM Platform. In the maintenance and management of extra-large bridges, the safety state of extra-large bridges is determined by the state of each component in the extra-large bridges. In the maintenance and management of super-large bridges, the inspection is divided by components, which are the most basic units for the operation and maintenance management of super-large bridges. Accurate description of the safety status of components is the basis of ensuring the overall safety status of super-large bridges. Manual inspection and automatic monitoring are the data sources to describe the safety status of components.

The manual inspection and automatic monitoring of super-large bridges are generally done by a third party. When the maintenance unit completes the manual inspection and prepares the manual inspection report, a large amount of raw data will not be given to management, but the visualization of BIM technology provides a good solution.

According to the routine inspection work of the extra-large bridge, it is convenient to fill in the Excel form with the corresponding information and save the data after manual inspection. Through secondary development, the BIM function of manual inspection of super-large bridges is realized and integrated into the Revit interface.

Through the manual inspection data of the Excel file, each component will be accurate, so that clicking can realize the view of the information of components in the model project of the super-large bridge, and the attribute parameters of each component will be added. Manually inputting the family parameters of model components is a conventional input method, which can be used when there are few component models. When there are hundreds of family components, this method is inefficient in adding family parameters. This paper will study Revit API, manage the project model through family manager, and add family parameters by using the AddParameter function of the FamilyManage class, so that the parameters of family components in the model can be added through secondary development, and then, the parameters of components can be added to the Revit interface, which is convenient for later use and greatly saves the time and energy of repeated labor.

In Revit software, each component has a separate ID number and a unique identification. In Revit software, the ID number of a component can be viewed after it is selected. On the contrary, the component can be located and selected by ID number. The secondary development process of the software is to identify components by their ID numbers. When modeling, each component has a professional name. In the form of manual inspection, the two identity attributes of the component should correspond one to one, which is convenient for computer reading and manual operation. Therefore, before the inspection, the ID and name tables of components are usually exported, which are used by manual inspection and maintenance.

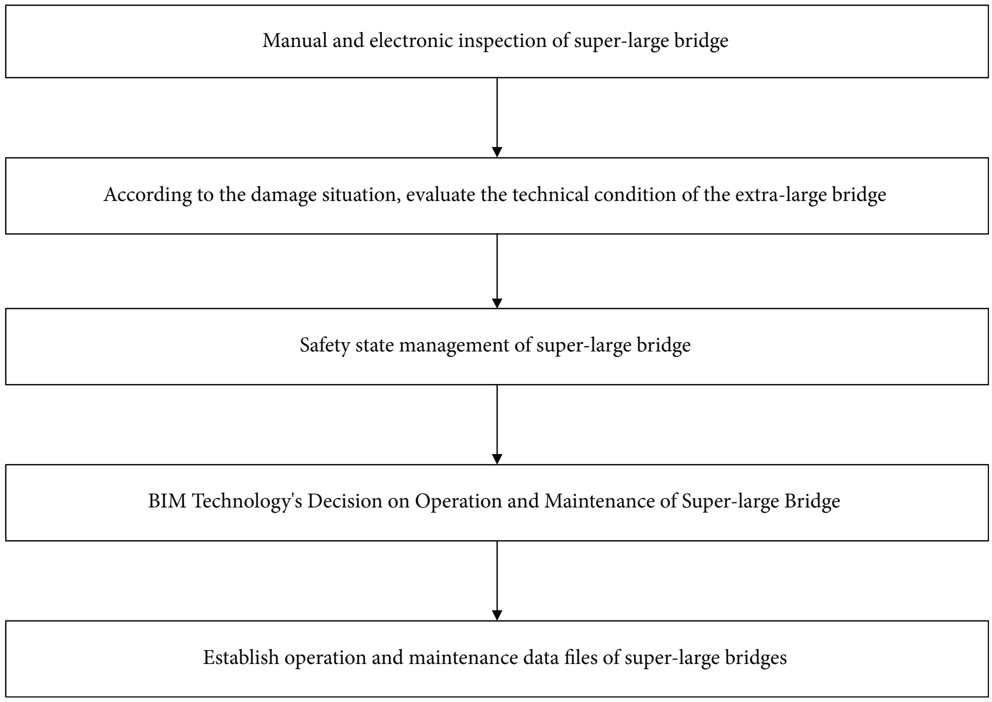

Figure 2: Maintenance process of super-large bridge.

When the Excel file format is fixed, the Excel file can be read by writing a program to realize the data import function. After the file is imported, the program will extract the ID number of each row in the Excel file, locate the component by this ID number, and then get each family instance parameter through the API, update the family parameter value to the software according to the Excel file format, and click the component to view the new parameters of the updated component.

When the manual inspection is finished, the software will rate the safety of each component. In the existing work, the safety level parameter of the component has been added. Through secondary development, the technical condition level of each component is marked and recorded in the parameter value. When the management and maintenance personnel repair and maintain the components, click the "Extract Manual Maintenance" button, and the software will identify the safety level parameters of all components in the model. The components with different levels will be placed in the predefined list container in the program and displayed in the window through the Revit dialog box for managers to use. The main parameters of the maintenance components include the ID number, name, disease situation, maintenance method, and other information.

The above method realizes the interaction and management of manual inspection data, and the application of BIM technology does not need complicated system development. It only needs the model management capability of BIM platform software to manage the component information system and does not need manual secondary statistics, thus ensuring the integrity of the original data and improving the accuracy of manual inspection and operation and maintenance management. The use of BIM technology has improved the maintenance and management efficiency of super-large bridges and can also solve the problem of isolated information islands.

3.2. Automatic Sensor Monitoring Based on BIM Platform. In the process of operation and maintenance of super-large bridges, in order to grasp the safety status of super-large bridges in real time and efficiently, a large number of sensors are generally installed on components to automatically monitor the information of super-large bridges for decision makers to analyze. With the increase of service time of super-large bridges, a large number of different types of data will be formed, which will play an important role in the safety description of components. When these data are stored in the health monitoring database, it will easily lead to data separation, which will cause some difficulty and inconvenience for the maintenance and management of the super-large bridge. Through the information exchange, sharing, and integration of BIM technology, all the data monitored by sensors are managed through the BIM platform.

Through the secondary development of Revit, the sensor data can be read and visualized. In this paper, the Excel file of health monitoring data is used as the interactive file, and in the process of reading sensor data, Revit is used to operate the files in the folder, so as to realize the integration of the Revit and Windows file system, and the data in the Excel file is displayed by the Windows Form program. When reading Excel files, the contents of Excel files are obtained (1) by reading DataSet, (2) by storing the contents of Excel files in rows through DataTable, (3) by other methods, and by defining a class to store the data in each row, the stored Excel files are bound to DataGridView for display. Figure 3 shows the reading and visualization of sensor data.

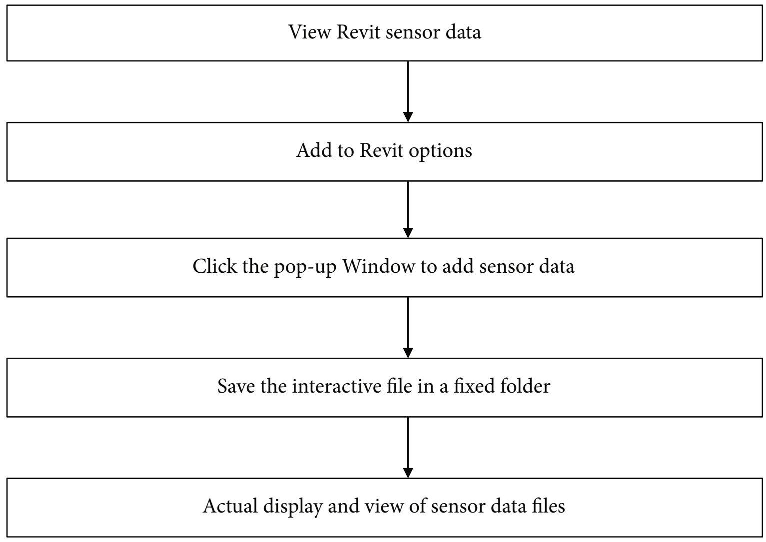

Figure 3: Reading and visualization of sensor data.

3.3. Application of BIM Technology in the Maintenance of Extra-Large Bridges. The maintenance of super-large road bridges is an important part of road safety; if the maintenance is not in place, it will cause serious disaster problems. In the maintenance and reinforcement work of the road bridge, the damage to the original structure should be avoided as far as possible. After the maintenance work is completed, the treatment effect is evaluated through the comprehensive evaluation system. In this paper, based on the BIM comprehensive platform and the actual situation on site, the maintenance and health files of the super-large bridge are gradually established to ensure that every disease is recorded, so as to provide reference experience, save manpower and material resources, improve maintenance efficiency, form maintenance records, and realize visual cloud trace management.

4. Conclusion

As the key node of highway traffic in China, the super-large bridge is the most important infrastructure of the country. Taking the highway bridge as the research object, on the basis of analyzing the maintenance management of bridges in China, this paper puts forward the monitoring and maintenance of bridges based on BIM technology, realizes the three-dimensional visual information management system of bridges, and improves the maintenance efficiency. Main research results are as follows:

(1) Based on the platform of BIM application in Revit, the application of BIM technology in the operation and maintenance management of super-large bridges has been established, and the related BIM modules have been developed. The main functions such as manual inspection, component safety management, and sensor data interaction have been realized, which greatly improves the efficiency of operation and maintenance management of super-large bridges

(2) By combining the manual inspection data with the model, the data integrity of the whole life cycle of the super-large bridge is continuously improved, and the visual expression of the manual inspection data is realized by using the visual characteristics of BIM technology, so that the expression of complex data is simple and direct. Through the integration of the Windows interface, file operation, and Revit, file addition and data display are realized through secondary development. In the Revit software, the query and extraction of sensor automatic monitoring data are realized

(3) Through the research on the application of BIM technology in the maintenance of extra-large Bridges, the method of combining the maintenance of extra-large bridges with BIM technology has been realized; the application of BIM technology in the design, construction, maintenance, operation, and maintenance stages of extra-large bridges has been explored; and certain results have been achieved. The application practice of BIM technology in the whole life cycle of extra-large bridges has been applied. It provides an efficient information management mode of the large bridge, so that the information value can be fully brought into play

Data Availability

The figures used to support the findings of this study are included in the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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