Research Progress of Structural Health Monitoring Based on BIM Technology

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Abstract. Structural health monitoring technology is one of the effective means to ensure the reliability of the structure, it is of great significance to the subsequent operation and maintenance of the structure to detect and identify the deterioration and damage of the structure during the service period, and realize the early warning and dynamic evaluation of the structural safety. Under the background of the rapid development of computer and other information technology, BIM technology is increasingly used in the field of structural health monitoring because of its good coordination, simulation, optimization, visualization, and graphing characteristics. This paper expounds and analyzes the research and application of structural health monitoring technology, BIM technology and structural health monitoring system based on BIM technology, and points out the technical and application problems that need to be solved urgently in the development of this field.

Keywords: Structural health monitoring technology, BIM technology, BIM visualization, Structural health monitoring.

1. Introduction
The hazards caused by structural safety accidents have sounded the alarm for the construction industry. Structural damage identification has attracted more and more scholars' attention. In-depth research on the visualization of structural health monitoring based on BIM technology is of great significance. First, it is not only conducive to the automatic processing and analysis of massive and complex monitoring data, improving the timeliness and accuracy of monitoring data, and realizing dynamic structural safety early warning and risk assessment, which is of great significance to the subsequent maintenance and operation of the structure. Secondly, BIM technology has good functions of coordination, simulation optimization and visualization. it is possible to construct a monitoring and management system that contains the full information and life cycle of the project. Through the combination with information technology, it will certainly cause a great change in the direction of informatization, intelligence and coordination of the construction industry.
2. Background
With the vigorous development of economy and the rapid progress of science and technology, human's exploration of the construction industry has been constantly pushed forward, showing the characteristics of diversified architectural forms and complicated internal space of the structure. Such as the Bank of China Tower, the National Grand Theater, the National Stadium Bird’s Nest, Guangzhou Opera House, Jinmao Tower, super high-rise buildings and other large and complex structural projects. Within the design service life of the building structure, due to the particularity of the force and the complexity of the structure, the comprehensive influence of human factors such as design and construction and external factors such as the environment and accidental effects, it is easy to cause structural degradation that is not conducive to overcoming its own damage[1]. In recent decades, the engineering accidents of continuous destruction or collapse caused by the failure of building structure due to self-damage and material deterioration are shocking. Many infrastructures and large and medium-sized buildings are in urgent need of a structural health monitoring tool to effectively ensure the dynamic evaluation of the performance and reliability of structures under the ultimate limit state and serviceability limit state. Structural health monitoring will be the focus of research in the field of architecture.

3. Research status

3.1. Research status of structural health monitoring.
Structural health monitoring technology uses the structural response detected by sensing equipment to evaluate the degree of structural damage and locate the damage location[2]. Structural damage identification is the core of structural health monitoring[3]. The goal of structural health monitoring is mainly divided into four levels. First, it is to identify whether there is damage in the structure, then conduct damage location and damage category analysis, judge the degree of damage of the engineering structure, and finally evaluate the future service life of the structure[4]. In actual engineering, structural monitoring is susceptible to many uncertain factors, such as low sensitivity to low-level structural damage, incomplete data acquisition by sensors, and noise interference in measurement signals, the structural damage identification methods, Monitoring data analysis and processing needs further research and development. Limin Sun et al.[5] introduced big data technology in the processing and analysis of bridge structure monitoring data to realize the information interaction between automatically collected monitoring data and externally entered monitoring data, and use big data technology to efficiently analyze large amounts of monitoring data to fully understand the safety status of the structure and the identification of possible damages provide technical support for the detection of damage to the bridge structure. Xuan Tang et al.[6] studied the health status of monitoring sensors for underwater shield tunnel structures that have been in service for many years. The study found that both optical fiber and vibrating string sensors could not continue to accurately reflect the structural safety of the tunnel after many years. Therefore, structural monitoring and sensing equipment should focus on the redundancy and substitutability of sensors, as well as the management and maintenance of sensing equipment during structural operation, so as to provide accurate monitoring information for structural safety assessment. Chen Yang[7] conducted a detailed analysis of the optimal placement method of structural health monitoring sensors, and expounded the key issues that need to be solved urgently in the field of modern sensor optimal placement, and provided reference and inspiration for the optimal placement plan and technology of structural health monitoring sensors. Jian Tang et al.[8] elaborated on the advantages and disadvantages of the existing structural damage identification technology, and made detailed analysis on the vibration and modal analysis theory, wave-based transmission theory, impedance technology, intelligent algorithmic neural network, genetic algorithm and signal processing technology. It provides new inspiration and thinking for the current development of structural damage identification technology. Rohan Soman et al.[9] proposed a novel index for damage monitoring based on cumulative power electromagnetic interference technology, and applied EMI technology to structural health monitoring based on
experiments, so as to verify the applicability of impedance technology in monitoring low-level damage. Sérgio Oliveira et al.[10] relied on the Cabril Dam earthquake and structural health monitoring, and focused on the automatic modal recognition of the earthquake and structural health monitoring system, the automatic seismic vibration monitoring, and the structural integrity control damage monitoring to achieve safety control and damage monitoring management of large dams.

The research and analysis of monitoring data processing methods, monitoring sensing equipment and structural damage identification technology by many scholars above have promoted the continuous improvement and development of structural health monitoring technology. In order to improve the daily monitoring and safety warning of the current operating engineering structure, not only need the support of various advanced sensing device, also need to make sure that in the structure of long period monitoring, the mass of the integration of monitoring data, analysis and processing, avoid losing may reflect the change rule of structure state dynamic data information, so as to improve the timeliness and reliability of structure safety analysis of early warning.

3.2. Research status of BIM technology.

The building information modeling is a powerful building information platform used to manage complex building information and can be used for virtual visualization in the complete building life cycle[11]. It has good visualization, interoperability and information exchange functions[12]. BIM can first be defined as a digital representation of a building, a three-dimensional model for a building, or a repository of project information. BIM can also be defined as a collaborative tool. When BIM extends from design to construction, and building facility management and maintenance, a new level of interoperability and collaboration can be achieved[13]. BIM technology first originated in the United States and has been developing rapidly in the United States, Europe, Japan and other countries. During the "Eleventh Five-Year Plan" period, BIM technology was included in the key projects of the National Science and Technology Support Program[14]. Since 2010, a research upsurge on BIM technology has been set off across the country. The research on BIM technology can be divided into three categories: the first category is basic technology research, such as the research of BIM working system with Industry Foundation Classes standard as the data interface; the second category is phased program research, how to use BIM technology to coordinate collision problems when arranging professional pipelines such as HVAC; the third category is engineering application research, such as the application of BIM technology in tunnel structures and the application in prefabricated engineering[15].

Yang Zhang[16] studied the engineering information management and the BIM model based on the IFC standard architecture, It has solved BIM-based 3D model construction, information extraction and fusion of BIM model, complete BIM data storage and analysis, etc. A building information integrated management platform based on BIM technology is developed to effectively improve the utilization efficiency of building engineering information resources. Fig.1. It is a diagram of the relationship between the building information model and the IFC international standard data information exchange.
Danxue Hou[17] applied BIM technology to the pipeline arrangement project of a health center, analyzed and calculated the pipeline collision detection data with the help of mathematical modeling factor analysis method, explored the collision law of typical areas, and used it as a reference for the design of the optimal avoidance scheme of BIM model pipelines, so as to avoid pipeline collision to the greatest extent. Shuang Wu[18] based on a university dormitory in Xi'an area, combined BIM 3D modeling with building energy consumption analysis software, and used BIM technology-based energy consumption simulation analysis to obtain the optimal scheme of building energy conservation design aiming at green and low energy consumption. It can be seen that the use of BIM technology to analyze building performance and achieve low-consumption and energy-saving green building design will become the development direction of deepening green technology[19]. Lidong Zhang[20] used a prefabricated residential project as a background, expounded the application of BIM technology in the whole life cycle of prefabricated structure design, construction simulation, site management and deepening design, etc. thus realized the efficient design of prefabricated structures, standardization of construction sites, coordination of management information, and deepening of design simulation. This will provide reference value for the development and promotion of BIM technology in prefabricated buildings.

As mentioned above, under the vigorous promotion of my country's relevant policies, BIM technology has already had many research results in engineering, which has greatly promoted the intelligentization and information integration of the construction industry. However, the combination of BIM technology and the construction field still needs to be further explored and studied, such as how to effectively combine BIM technology with the calculation method of monitoring data related to structural monitoring, structural damage identification technology, and the optimal arrangement of monitoring sensors, so as to realize the real-time and accurate safety monitoring of structural deterioration during service.

4. Structural health monitoring based on BIM technology
The promotion of BIM technology is still an important source of power to promote the all-round transformation of the construction industry, which will also promote the transformation of the structural health monitoring field from the original rough work mode to the refined work mode[21]. The construction of the BIM model and the traditional structural monitoring technology are integrated to realize the visualization of the three-dimensional model of the monitoring system, the interaction of monitoring information and the sharing of resources, and provide guarantee for the accuracy of operational structural risk early warning and decision-making. Xianguo Wu et al.[22] studied the architecture of the subway structure health monitoring system based on BIM technology, explained the transmission plan and analysis and processing of various sensor equipment monitoring data, and provided reference and guidance for the design of the health monitoring and management system of
the same type of operating tunnel structure, the selection of data transmission plans, and the classification of monitoring and early warning. Xuechen Jin[23] developed an intelligent visualized fire rescue decision-making platform. Once the structure has a fire, the location of the fire point will be displayed in the BIM model. The location of the trapped person is determined according to the indoor wireless positioning function based on Long Range, and an optimal evacuation path is planned using Dijkstra’s algorithm for timely implementation coordination between the fire rescue command center and the fire scene. Bo Yang[24] conducted in-depth theoretical research on the display of information of important parameters such as crack, deflection, stress, beam inclination, beam landslide and pier settlement in BIM model and the expression of monitoring information based on IFC standard in bridge structural health monitoring, which has promoted the development of bridge structure management toward informatization, intelligence, and coordination. Hongying Chen[25] combined a bridge project with a steel-concrete composite beam structure as the main girder, and used the development of 3D modeling software Revit and C# to establish a bridge structure health monitoring and early warning system, which realized the wind speed, temperature, and vibration of the bridge structure. The visual display of monitoring parameters such as deformation and stress provides an important reference for the monitoring and management of the same type of bridge structure system. Xiaojun Kao[26] used BIM three-dimensional modeling software Revit and Civil 3D designed a foundation pit engineering information construction management platform based on BIM technology. The platform uses BIM technology to have good visualization, interoperability and information exchange functions. Carry out design collision coordination in the construction phase in advance to avoid construction delays. Zhigang Liao et al.[27] developed a foundation pit construction monitoring system based on BIM technology. The research focuses on the automatic collection of foundation pit monitoring information, integrated analysis, calculation processing and report output, which improves the information and intelligence level of foundation pit monitoring and effectively guarantees the safety and stability of foundation pit excavation. Jing Li et al.[28] further explored the application of dam safety monitoring based on BIM technology, used CATIA software to establish a three-dimensional building information model of the dam project, applied the monitoring results based on BIM technology to different stages of the dam project, and finally formed a three-dimensional monitoring system for the full life cycle of the dam. Lanshuang Shi[29] constructed a dam engineering deformation monitoring model based on BIM technology, used a smart network to cover the 3D dam model to determine the scope of structural monitoring. Eliminated the singular values in the monitoring data and use the interpolation method to process the data gaps to improve the accuracy of structural monitoring, finally realized the visualization of the deformation monitoring of the dam project. Shuai Xiong[30] developed a health monitoring system with a large-span spatial structure, the combination of BIM technology information integration and finite element model analysis is proposed and applied to the actual project of the large-span steel structure of the Haikou East Railway Station, which verifies the feasibility and accuracy of the system. Qiang Xu et al.[31] rely on the Xixian Youth Pioneer Park project to build a prefabricated building monitoring management system based on BIM technology, the system provides timely and intelligent early warning of possible damage and large deformation of the fabricated structure, which helps to improve the construction level of the fabricated structure and its safe operation during its service. Yun Shi et al.[32] developed a structural health monitoring and management system for the construction of super high-rise and large-span spatial structures based on BIM technology. By fusing the automatic collection of system monitoring information with on-site monitoring data collection, the circulation and linkage of monitoring information during the construction process are improved, thus the dynamic monitoring and early warning of the structure can be realized.

Many of the above scholars have conducted in-depth research on the structural health monitoring system based on BIM technology, the application of BIM visualization and health monitoring system has a very positive effect on improving the accuracy, intuitiveness and interaction between three-dimensional building models of the monitoring information management platform[33], which greatly
promotes the intellectualization and informatization and visualization. The structure of the structural health monitoring management system based on BIM technology is shown in Fig. 2

![Fig. 2 Frame of structural health monitoring system based on BIM technology](image)

5. **Visualization of structural health monitoring**

With the widespread application of BIM technology in the field of construction, structural health monitoring data has completed the transition from two-dimensional display to three-dimensional visualization. For increasingly complex, large and irregular building structures, the amount of sensor monitoring data is huge and the monitoring cycle is long. Manual processing and analysis of data is time-consuming and it is difficult to ensure the timeliness of monitoring data. With its advantages in visualization and synergy, BIM technology breaks the lag of traditional monitoring data analysis, effectively improves the efficiency of monitoring information analysis and processing, and provides reliable guarantees for structural damage analysis, safety risk assessment and early warning decision-making. The specific application of BIM technology in structural health monitoring is shown in Table 1.
Table 1. Application table of BIM technology in structural health monitoring

| Phase                        | Purpose                                           | Application                                      |
|------------------------------|---------------------------------------------------|-------------------------------------------------|
| deepening the design phase   | component deepening design and pre-assembly       | collision check energy consumption analysis     |
| construction phase           | ensure the safety of the entire construction process from the beginning of the site construction to the end of the construction | construction safety management construction deepening design construction schedule management |
| operation and maintenance phase | ensure the safety of the operating structure       | carry out risk assessment and early warning of the safety state of the structure to improve the reliability of the structure |

6. Conclusion

Combining BIM technology and structural health monitoring technology, and developing time-sensitive monitoring management and information integration systems are the research hotspots in the direction of structural health monitoring visualization. The current practical application of structural health monitoring based on BIM technology is still immature. There are still technical and application problems that need to be solved in the development of this field, and further research is needed:

6.1. Get rid of model constraints and strengthen data analysis.
The monitoring data of the structure is the scientific basis for determining the stress state of the structure, identifying the degree of structural damage, and evaluating the service life of the structure. Building information modeling is a technical means, not an end[34]. When constructing the system, we must pay attention to the depth of monitoring information processing, and use mathematical analysis related to mathematical statistics such as variance analysis, regression analysis and other mathematical analysis methods to increase the accuracy of monitoring data analysis and processing.

6.2. Optimize sensor algorithms and enhance equipment management.
The health monitoring of large and complex structures often requires the deployment of large-scale sensors, and whether the existing classical algorithms and optimization algorithms for sensor placement can obtain the optimal placement plan still requires further theoretical analysis and numerical simulation analysis. The management and maintenance of sensing equipment in service in harsh and complex environments has not received extensive attention., the data error between the ideal sensor working state and its real working state will inevitably affect the accuracy of structural monitoring.

6.3. Carry out basic research and realize resource sharing.
The future development trend is bound to strengthen the development of BIM software system to realize BIM resource sharing, to realize the real-time interaction between monitoring information and BIM models, it is also necessary to establish a data mapping mechanism between the IFC data model and the monitoring information platform. The research and development of functions such as graphics, images, and virtual component libraries needs further development.

6.4. Strengthen talent training and give full play to cloud advantages.
The lack of professional BIM talents is an important factor restricting the development of BIM, and it is necessary to strengthen the multidisciplinary interactive training of BIM talents. Leverage the cloud advantages emerging technologies such as big data, cloud platforms, and the Internet of Things to provide new development momentum for the field of structural health monitoring.
Acknowledgments

This work was financially supported by Doctoral Foundation of the Shandong Natural Science Foundation (ZR2018BEE038), National Nature Science Foundation of China (51678277), National Nature Science Foundation of China (51778372), Guangdong Provincial Key Laboratory of Durability for Marine Civil Engineering (GDDCE15-05), A Project of Shandong Province Higher Educational Science and Technology 2015 (TJY1504), and the Doctoral Foundation of University of Jinan (XBS1437) fund.

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