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Integration of Building Information Modeling and Structural Health Monitoring for Effective Building Management-A Review

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ABSTRACT

Structural Health Monitoring (SHM) is used to learn more about the condition of buildings and bridges to identify any possible damage. Conventional monitoring techniques can include individual data collection, manual monitoring and structural monitoring, which can make it challenging to keep track of all the data at once. Building Information Modeling (BIM) provides a digital solution to the storage of structural information and integrate it with monitoring outcomes.

This paper summarizes the existing five published studies related to structural health monitoring in BIM based researches. The research works include bridge construction monitoring, updating of finite element model, development of digital twin, remote sensing, sensor management and sensor system design. Structural assessment is supported by the use of different tools and methods, such as BIM models, finite element analysis, laser scanning, cameras, wireless sensors and Internet of Things (IoT) systems. The results demonstrate that BIM can contribute to organizing monitoring information, visualize the modifications of the structure, enhance the structural models accuracy and assist decision making for maintenance. The reviewed studies also reveal that integration of various software systems and the integration of sensor data to BIM models are still difficult. Some methods have only been applied to specific structures, and they must be tested further to be used more widely. This paper marks the inherent advantages of using BIM in SHM and catches the key challenges to be solved in order to establish more practical and reliable monitoring systems.

Key Words: Building Information Modeling, Structural Health Monitoring, Digital Twin, Finite Element Model, Sensor Integration, Structural Safety.

INTRODUCTION

Structural safety is one of the key aspects of civil engineering. Buildings and bridges are subjected to vehicles, weather, deterioration of materials, and other factors that may impact their performance over the years. These changes can be expensive to repair or cause safety issues if not detected in the early stages. Structural Health Monitoring (SHM) is a method for examining the state of a structure through the measurement of data, including strain, vibration, stress and deformation. The data is useful to engineers to determine the behavior of a structure and whether maintenance or additional inspection is required.

In many projects, there are various systems for structural information, sensor readings, inspection reports and computer-based analysis. This can sometimes make it challenging to relate the information and determine which sections of a structure need attention. Building Information Modeling (BIM) can contribute to solve this problem. BIM generates a virtual model that encapsulates data on the components of a building or bridge. If monitoring information is connected to this model, engineers can see the details of the structure and information obtained from monitoring in an organized manner.

There have been some recent studies that have investigated the integration of BIM with SHM in various ways. Li [1] examined the application of BIM in predicting and monitoring the deformation and stress in bridge construction. Cruz et al. [2] designed the HH-Structures platform for integration of BIM information with finite element models and for the assessment of historical structures. A method for updating FEM with monitoring information and tools through BIM software was proposed by Guarino et al. [3] These studies are directed toward the improvement of the structural analysis and making digital models more functional in order to be able to understand the real structural behaviour.

The remote monitoring and sensor management have been explored in other works. To investigate the behaviour of a reinforced concrete building in an experiment of removing the columns, Bai et al. [4] employed cameras, laser scanning, wireless accelerometers and a digital twin. Fawad et al. [5] proposed a BIM-based management framework of a bridge monitoring system, comprising of a finite element model and sensor data. Gragnaniello et al. [6] suggested the planning and placement of SHM systems based on BIM, focusing on the information needs and the validation of information shared among project stakeholders.

While the above studies demonstrate the potential of using digital tools in structural monitoring, the approaches and goals vary. Some are devoted to monitoring at construction phase, others to existing bridges, historical buildings or to the behavior of the buildings when they are part of a controlled experiment. The creation of a joint database from the information obtained from sensors, BIM models and structural analysis software is also not easy. Furthermore, one method might not be applicable in the same manner in each building or bridge.

The aim of this review is to review these six studies, clarify the methods and key results of these studies, and discuss the issues that require further research. This review concentrates on the role of BIM in the following areas—data management, structural assessment, damage identification, and maintenance planning. It also highlights the importance of improved software linkages and more robust data exchange and testing of various structural systems.

LITERATURE REVIEW

Li [1] conducted stress and deformation monitoring & optimization in bridge construction by using BIM. To simulate construction stages, the study employed a bridge model, and to predict structural behaviour, the model was used by following the steps of the construction process. Next, it was decided that sensor technology and data collection should be considered for real-time monitoring. They also claim that error of stress prediction has been reduced by 20% and error of deformation prediction by 15% when compared to traditional methods. It also provides the results of stress and deformation reduction due to changes in construction sequence and parameters. The findings indicate that BIM-based simulation and monitoring can assist the engineers to plan construction work and manage the risk of structures. The information provided, however, is for the method used in the study and should not be assumed to be applicable to all bridges.

Cruz et al. [2] had developed a new class of structures, called HH-Structures, for monitoring and assessment of historical structures. The platform links BIM information to finite element models and shares data using the usual data exchange via IFC format. The workflow contains information regarding the structure, non-destructive testing, laser-scanned point clouds, visual inspection and vibration measurements. It's also good for calibration of an experimental model. The authors applied their approach in a case study of a steel bridge. The work tackles an issue that has been a concern: it's not always smooth data transfer between BIM and structural analysis software. The paper also has some limitations, such as relying on some commercial software.

Guarino et al. [3] studied the use of monitoring data for improving FE models. They link Revit, Python-based processes with finite element analysis in Abaqus with their FEMUP approach. The structural model is updated using experimental information obtained from ambient vibration testing such as natural frequencies and mode shapes. This improves the model representation of the actual structure's behaviour. This study demonstrates the usefulness of BIM as a place to manage the structural information during a process of engineering analysis made with another tool. The main drawback is that the method needs to be further validated for other structures and conditions.

Bai et al. [4] the removal of a column was studied in a 6 storey reinforced concrete building. The team employed cameras, drones, LiDAR, wireless accelerometers and computer vision techniques to quantify structural motion and detect visible damage. Digital twins of the building before and after the removal of a column were used to assess the residual deformations in beams and slabs. This study demonstrates that the use of remote sensing, where access to each structural element is not possible, is valuable. But the remote monitoring may be impacted by visibility, dust, camera position, and equipment issues. The digital-twin results need, therefore, to be complemented with appropriate measurements and intelligent interpretation.

Fawad et al. [5] proposed an automated approach to monitor an existing bridge using BIM. The method adopts the finite element analysis, field load testing, visual programming, BIM-based sensor model and an Internet of Things platform based on Arduino. It enables the control of the monitoring devices location and information via the digital model. This can make information from sensors more readily available and organized.

CONCLUSION

This review of six studies shows how Building Information Modeling (BIM) can help monitor the health and safety of buildings and bridges. By combining BIM with sensors, structural analysis, remote sensing, and digital twins, engineers can better understand how structures behave, detect possible damage, and plan maintenance. However, some challenges remain, including difficulties in sharing data between different software, ensuring accurate sensor readings, and keeping digital models up to date. Future research should focus on developing a simple and reliable system that combines these technologies and tests them on real buildings and bridges. Overall, BIM has the potential to make structural monitoring more effective, improve safety, and support better maintenance decisions.

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