Title: BIM-based Framework of Bridge Health Monitoring Supported by Immersive and 3D Reconstruction Techniques for Analytical and Asset Model Updates

Abstract

In recent times, digital transformations and Industry 4.0 have revolutionized bridge monitoring and inspection procedures by providing smart solutions. The use of smart Structural Health Monitoring (SHM) is one such solution that is becoming powerful with the competencies of Building Information Management (BIM) tools, Artificial Intelligence (AI), Internet of Things (IoT), and Virtual/Augmented/Mixed (VR/AR/MR) technologies. This PhD research has carried out a detailed study on the use of such smart health monitoring procedures and provided some state-of-the-art findings in this domain.

The research provides a state-of-the-art review of the literature available for SHM of bridges from the design phase to the development of immersive solutions for SHM. The study covers the exploration of Bridge Management Systems (BMS) in detail with the specifics of technological advancement in BMSs over the period of time. The exploration of the BMSs discusses the use of traditional bridge inspection methods for the extraction of bridge health data which are replaced by the dedicated SHM system due to advancements in the analytical and 3D modeling techniques.

In the quest to use digital technologies for BMS, the study explores the applications of BIM methodology for an in-depth analysis of its application for the management of bridge assets. It helps the understanding of basic principles of BIM tools that can be applied to the SHM domain to collect, manage, and analyze the structural health data and helps in predictive decision-making. This study emphasizes the use of BIM technology to transform bridge analytical modeling techniques by integrating 3D models with FEM methods. This integration enhances full-scale structural damage mapping, emphasizing the critical role BIM plays in bridge health data management. Further, the research proposes a novel technique of BIM-based automated FE modeling. In a case study, a Visual Programming Language (VPL) interface is used to retrieve data from the BrIM model and convert it into a set of curves and points for automated FEM model generation. This approach facilitates efficient bridge condition analysis and health information management.

The study also explores the concepts of Virtual, Augmented, and Mixed Realities (VR/AR/MR) for the visualization of bridge concepts planned to be constructed in the future. This approach pioneered the use of such technologies for the assessment of bridge design concepts. To further integrate the VR/MR tools with the SHM systems of the bridges, applications of Internet of Things (IoT) technology are explored. This exploration results in the possible solution of developing an online web platform for bridge SHM systems that can utilize wireless sensors not only for bridge health monitoring but also for periodic maintenance of bridges. Further exploration of this domain provides the possibilities of integrating MR technology with this web based SHM system using the platform of BIM methodology. This way the integration of several advanced tools like SHM, BIM, IoT, and MR yields a novel Immersive Bridge Digital Twin Platform (IBDTP) that can facilitate the fusion of virtual and physical assets and can perform real time automated SHM of the bridge in the immersive environment.

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The IBDTP improves infrastructure management by overcoming the limitations associated with traditional SHM methods, particularly in terms of data management and the visualization of bridge monitoring data. It provides a comprehensive framework for the digital twining of infrastructure, enabling proactive decision-making by infrastructure managers. The IBDTP's functions can be potentially scaled for different types of bridges and critical infrastructure, offering a promising avenue for improving traditional SHM practices. The research suggests that the developed platform can serve as a base to guide future practices of digital twinning in the field, contributing to advancements in infrastructure monitoring and decision-making.

The outcomes of this study have the potential for broader applications, particularly in automation processes and the implementation of digital twins within the construction sector. Although the primary emphasis lies in the domain of bridges, it's important to acknowledge that the principles of this research are transferable to other structural domains, including buildings and various infrastructure projects.

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