Using Sensors for Structural Assessment Through BIM in the Life Cycle of Buildings

Jorge Pablo Aguilar Zavaleta*

Faculty of Engineering and Architecture, Professional School of Architecture, César Vallejo University, Peru

*Corresponding Author
Jorge Pablo Aguilar Zavaleta, Faculty of Engineering and Architecture, Professional School of Architecture, César Vallejo University, Peru.

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Abstract

Using sensors for structural assessment through Building Information Modeling (BIM) represents a cutting-edge approach in the architecture, engineering, and construction (AEC) industries, enabling enhanced monitoring and management of building performance throughout their life cycle. By integrating realtime sensor data into BIM frameworks, stakeholders can obtain comprehensive insights into structural health, energy efficiency, and operational functionality. This integration not only supports the preservation of heritage structures but also improves the safety and efficiency of modern buildings, making it a notable development in contemporary construction practices.

The evolution of this integration began in the early 21st century, as advancements in sensor technologies and data analytics laid the groundwork for sophisticated structural health monitoring (SHM) systems. The fusion of BIM with SHM facilitates proactive maintenance strategies, helping to identify and mitigate potential structural issues before they escalate into significant problems. Various case studies, including projects like the Azzone Visconti Bridge in Italy and the Monserrate Palace in Portugal, illustrate the effectiveness of this approach in both new and historic structures, demonstrating improved safety outcomes and streamlined maintenance processes through realtime data acquisition and analysis.

Despite its numerous advantages, the integration of sensors with BIM also faces challenges, such as ensuring interoperability between different software systems and maintaining data accuracy. Ongoing research aims to address these hurdles while exploring the potential of emerging technologies, including artificial intelligence, the Internet of Things (IoT), and digital twin applications, to further enhance the capabilities of BIM in structural assessment. As the field continues to advance, this innovative methodology is expected to play a crucial role in shaping the future of building life cycle management, emphasizing sustainability and resilience in construction practices.

The notable shift towards incorporating sensor technologies into BIM frameworks has raised important discussions regarding data privacy, security, and the need for standardized practices across the AEC sector. These concerns underscore the importance of ongoing collaboration among industry professionals, researchers, and policymakers to ensure that the benefits of this integration can be fully realized while addressing the complexities it entails.

Keywords: BIM, Sensors, Cycle of Buildings, Operation and Maintenance

1. Introduction
1.1. Historical Background
The integration of Building Information Modeling (BIM) and structural health monitoring (SHM) has evolved significantly over the years, driven by the need to preserve heritage structures and enhance the safety and efficiency of modern buildings.

Historically, the concept of using technology for structural assessment began gaining traction in the early 21st century as the architectural, engineering, and construction industries sought

innovative solutions to manage the complexities of building design and maintenance.

1.2. Early Developments in BIM
The initial developments in BIM can be traced back to the late 1990s, with the technology designed to facilitate digital representations of physical and functional characteristics of buildings. It enabled stakeholders to visualize and manage building data throughout the life cycle of a project, from design to operation and maintenance [1].

As the capabilities of BIM expanded, its application in heritage building preservation became a focal point, with various studies highlighting its potential in reviving cultural values through effective management strategies [2].

1.3. Integration with Structural Health Monitoring
The formal integration of SHM with BIM began to take shape around 2010, when advancements in sensor technologies and data analytics allowed for more sophisticated monitoring systems to be implemented in existing structures. This period saw the development of various guidelines and literature addressing the use of BIM for assessing and monitoring the structural condition of buildings [3,4]. Notably, the introduction of historical BIM (H-BIM) models revolutionized the approach to managing and preserving historic buildings by combining traditional architectural knowledge with modern data analysis techniques [5].

1.4. Case Studies and Practical Applications
Several compelling case studies exemplify the successful application of integrated BIM and SHM systems. For instance, the Azzone Visconti Bridge in Italy employedan H-BIM model in conjunction with SHM data to monitor structural movements during load tests, enhancing long term monitoring capabilities of historic structures[5]. Similarly, the Monserrate Palace in Portugal implemented a low cost sensor based BIM system to acquire realtime data on structural health, demonstrating the efficacy of combining advanced monitoring with heritage conservation efforts [5].

1.5. Advances and Future Directions
Recent advancements in artificial intelligence and data analytics have further strengthened the integration of BIM with realtime sensor data, allowing for more accurate and proactive management of building health [6]. The shift towards smart buildings equipped with sophisticated monitoring systems reflects a growing recognition of the importance of continuous assessment and maintenance, particularly for heritage structures that require meticulous preservation efforts [7]. As the technology continues to evolve, the potential for enhanced collaboration between architectural practices, engineering, and data science will drive further innovations in the field of building life cycle management.

2. Methods
2.1. Sensors in Structural Assessment
Overview of Structural Sensors
Structural sensors are essential tools used to monitor movements, deformations, stresses, and strains within buildings and civil engineering structures. These sensors come in various types, allowing for tailored monitoring solutions that address specific challenges and budgetary constraints [8,9]. Their primary role is to ensure the integrity of structures, particularly during renovation, upgrading, or nearby construction activities, while also facilitating long-term health tracking and maintenance planning [8,9].

2.2. Types of Structural Sensors
Deformation and Displacement Sensors
Deformation sensors, such as fissurometers and inclinometers, are utilized to monitor relative displacements and small changes in structure inclination, respectively.

Fissurometers can achieve precise measurements ranging from 0.1mm to 0.01mm, which is crucial for tracking the opening of cracks or joints in structures [8]. Inclinometers offer accuracy of approximately 0.1mm/m in detecting deviations from vertical, thus providing valuable data on structural shifts [8].

2.3. Vibration Sensors
Geophones and accelerometers are employed to measure vibrations within structures. These sensors detect the frequency and magnitude of vibrations, providing insights into structural behavior under various loading conditions [8].

2.4. Pressure and Settlement Sensors
Pressure sensors measure the forces acting on structural elements, offering crit- ical data for assessing stability and load distribution, especially in foundations and bridges[9]. Hydraulic settlement gauges provide a straightforward method for monitoring settlement or heave at multiple points within a structure, making them particularly useful in underpinning projects [8].

2.5. Fiber Optic Sensors
Fiber optic sensors are increasingly prominent due to their ability to conduct contin- uous measurements of temperature and deformation along their length. Their high sensitivity allows for early detection of potential structural weaknesses, enabling pre- dictive maintenance strategies that mitigate risks associated with structural failures [10]. This capability positions them as integral components within a comprehensive structural health monitoring system [10].

2.6. Applications in Structural Assessment
The integration of structural sensors within the building's life cycle management significantly enhances the assessment process.

Nearby Construction Work: Monitoring ensures that existing structures remain stable and safe during adjacent construction activities.

Renovation and Upgrading Projects: Sensors provide realtime data on structural integrity, enabling informed decision-making and maintenance during renovations.

Detection of Structural Issues: Early identification of problems, such as cracks or misalignments, allows for prompt intervention, preserving structural integrity.

3. Future Innovations

The ongoing evolution of structural sensors, particularly through advancements in nanotechnology and materials science, promises even greater sensitivity and functionality. Innovations are likely to yield new sensor types that further enhance the ability to monitor structural health, thereby reinforcing their vital role in construction practices and sustainability efforts [10].

3.1. Building Information Modeling (BIM)

Building Information Modeling (BIM) is a transformative approach in the architecture, engineering, and construction (AEC) industry that allows for the digital representation of a building's physical and functional characteristics. At its core, BIM involves creating intelligent 3D models that encompass detailed data about materials, specifications, and system performance throughout a building's lifecycle, from design to operation and maintenance [11,12]. This methodology not only enhances visualization but also facilitates collaboration among various stakeholders, reducing errors and improving efficiency during the construction process [6,12].

3.2. Integration of BIM with Sensor Technology

The integration of BIM with sensor technology has emerged as a significant advancement in monitoring and managing buildings. As high-performance buildings increasingly incorporate sophisticated monitoring systems, the fusion of BIM with realtime data from sensors enables facility managers to gain comprehensive insights into building performance, including indoor environmental quality and energy consumption [7,10]. This synergy allows for proactive maintenance strategies and better lifecycle cost management by providing a clear picture of operational metrics, thus optimizing resource utilization and extending the lifespan of facilities [3].

3.3. Challenges and Future Directions

Despite its advantages, the implementation of BIM faces several challenges, particularly in accurately modeling smart components and integrating them with realtime data sources[6][12]. Current methodologies often lack clear guidelines for embedding these components within BIM models, leading to potential gaps in data representation. Future research must address these challenges by developing more accurate modeling techniques and enhancing the commercial applications of BIM technology, including improved sensor cost considerations and higher accuracy in data acquisition [6,12].

As the field continues to evolve, BIM is set to play an increasingly critical role in the lifecycle management of buildings, transforming how construction projects are designed, executed, and maintained [11,7 and 12].

3.4. Integration of Sensors and BIM

The integration of sensors with Building Information Modeling (BIM) represents a significant advancement in the management and assessment of building structures throughout their life cycle. This innovative approach enhances the capability to monitor and evaluate the condition of buildings in realtime, allowing for improved decision-making and operational efficiency.

3.5. Benefits of Sensor Integration

By supplementing BIM models with realtime data from environmental sensors, such as temperature and humidity, it becomes possible to create a rich User Interface (UI) that can mitigate health hazards within buildings and infrastructures [13,7]. This integration not only facilitates a comprehensive understanding of a building's energy performance but also aids in the identification of necessary improvements [14]. Moreover, the combination of BIM and Internet of Things (IoT) technologies fosters a shared data environment that enhances both energy and indoor environmental performance, ultimately leading to reduced operational costs [4].

3.6. Practical Applications

The practical applications of integrating sensors into BIM are exemplified in various studies. For instance, the integration allows for realtime monitoring of structural conditions, enabling stakeholders to receive immediate alerts regarding potential issues such as structural failures [15]. Furthermore, the implementation of a low-cost remote monitoring system demonstrates the feasibility of using BIM and IoT technologies for large-scale applications, potentially revolutionizing how structural health monitoring (SHM) is conducted [16].

4. Case Studies and Research Developments

Recent research has shown promising results in the integration of BIM with IoT sensors specifically for structural monitoring, particularly in the context of bridge structures [12]. This integration not only enhances the accuracy of data collected but also ensures that it is presented in a format that stakeholders can easily access and interpret. The incorporation of custom visual programming scripts into BIM allows for the dynamic updating of models based on realtime sensor data, further enhancing the analysis capabilities of building managers and engineers [17].

4.1. Challenges and Future Directions

Despite the advantages, the integration of sensors with BIM is still in its early stages, with many studies primarily focusing on the theoretical aspects rather than practical applications [18]. Challenges such as data sharing across networks, realtime updates of BIM visualizations, and interoperability between different software systems need to be addressed to fully realize the potential of this integration [19]. Future research should focus on developing more comprehensive frameworks that not only include sensor data but also enhance collaborative efforts among stakeholders in the construction and management sectors [20].

4.2. Applications in the Life Cycle of Buildings

Building Information Modeling (BIM) significantly enhances the management and assessment of buildings throughout their life cycle by integrating various data sources, including sensors for structural health monitoring. This approach facilitates more efficient design, construction, and operation phases, ensuring that buildings meet environmental and functional standards.

4.3. Design Phase

During the design phase, BIM allows architects and engineers to visualize different aspects of the building in a shared digital model. This collaboration helps identify potential issues and optimize designs before construction begins [21]. The use of sensors is particularly beneficial here, as they can be integrated early in the design process to provide realtime data on structural performance and environmental conditions. For instance, Montiel Santiago et al. highlight the importance of incorporating natural lighting and ventilation considerations into the building envelope design, which can be further enhanced through the use of data from sensors [16,6].

4.4. Construction Phase

In the construction phase, BIM provides a central repository for information, allowing for better coordination among various stakeholders, such as contractors and facility managers [21]. The integration of sensors during this stage can monitor the structural integrity of the building as it is being constructed. This monitoring ensures that any deviations from the planned construction methods can be addressed promptly, thereby reducing the risk of future structural failures [2,22].

4.5. Operation Phase

Once the building is operational, the data collected from sensors can be used for ongoing facility management and maintenance. The BIM model is updated with information about the building's systems and their conditions, which assists facility managers in planning maintenance activities effectively. For example, energy consumption data from the building's systems can inform strategies for improving energy efficiency, ultimately leading to reduced operational costs and lower environmental impact [23,21]. Furthermore, preventive maintenance scheduling, aided by sensor data, allows facility managers to anticipate repair needs based on usage patterns and structural performance, which can significantly extend the useful life of the building [22].

4.6. Demolition and Recycling Phase

At the end of a building's life cycle, BIM can facilitate the demolition process by providing detailed information about materials used and their structural integrity. This data supports the recycling and reuse of materials, contributing to sustainability goals. By utilizing a detailed data structure that includes sensor readings throughout the building's life, stakeholders can make informed decisions regarding material recovery and waste management, thus minimizing environmental impacts [16,6].

5. Results and Discussion
5.1. Case Studies

• **Azzone Visconti Bridge, Lecco, Italy**

The Azzone Visconti Bridge integrates a historic Building Information Modeling (H-BIM) model with Structural Health Monitoring (SHM) data to assess vertical movement during load tests. This project emphasizes data visualization, where monitoring data is linked directly to the 3D model, creating an intuitive interface for realtime observation. Furthermore, the model archives historical data, enabling multi-temporal analysis that facilitates comparisons between past and present conditions, thus enhancing long-term monitoring capabilities for historic structures[5]. Monserrate Palace, Sintra, Portugal.

At the Monserrate Palace, a low cost sensor based BIM system was implemented to acquire realtime data on structural health. Key features of this project include realtime data acquisition, where sensors monitor vibrations during both regular activities and extraordinary events. The collected data is stored within an H-BIM model, allowing for continuous assessment and management of the palace's structural integrity [5].

5.2. Laboratory Beam Model Study

In a controlled laboratory setting, a study was conducted on a beam model utilizing low-cost sensors connected to its digital twin. This setup enabled remote monitoring, with realtime data visualized within the BIM model. The findings from this case study illustrate that cost-effective sensor solutions are viable for structural monitoring applications, demonstrating the practical potential of integrating low cost technology in BIM environments [5].

5.3. Stura Bridge, Turin, Italy

The Stura Bridge project employed an integrated BIM-SHM system for automated structural monitoring. A BIM model was created in Revit and exported to Robot for structural analysis. The placement of sensors was automated using Dynamo scripts based on the monitoring requirements, facilitating efficient data management. The results were organized in Excel, resulting in a digital twin of the bridge that acts as a comprehensive tool for ongoing monitoring and evaluation [5].

These case studies collectively highlight the effectiveness of integrating BIM with SHM in both new and historic structures, showcasing improved safety and streamlined maintenance processes through realtime data acquisition and monitoring.

6. Conclusions
6.1. Future Trends

Anticipating future trends in sensor technology within the construction industry unveils a landscape shaped by continuous innovation, technological convergence, and a focus on sustainability. These emerging trends are poised to revolutionize construction practices, elevating efficiency, safety, and environmental consciousness.

6.2. Advancements in IoT and Connectivity

The Internet of Things (IoT) will continue to be a driving force in construction. Sensors embedded in various construction elements will communicate seamlessly through interconnected networks, enabling realtime data collection, analysis, and decision making. This connectivity will facilitate predictive maintenance, optimize resource allocation, and enhance overall project management [10,24].

6.3. AI and Machine Learning Integration

All driven analytics and machine learning algorithms will play a pivotal role in sensor data interpretation. These technologies will sift through vast datasets generated by sensors, identifying patterns, predicting structural vulnerabilities, and recommending preventive measures. This predictive capability will revolutionize maintenance strategies, reducing downtime and improving asset lifespan [10,25]. The integration of AI with sensor networks is expected to enhance the accuracy of monitoring tasks and provide deeper insights into structural health [3].

6.4. Augmented Reality (AR) and Virtual Reality (VR) Applications

The incorporation of augmented reality (AR) and virtual reality (VR) into the construction process is anticipated to transform the way projects are visualized and managed. These technologies will allow engineers and stakeholders to interact with digital models of buildings in a more immersive way, facilitating better understanding and communication of structural conditions and potential issues [10,24].

6.5. Digital Twin Technology

Digital twin technology, which involves creating realtime, live models of physical infrastructure, is set to revolutionize how structures are monitored and managed. By continuously collecting and analyzing data, digital twins enable proactive maintenance and optimization, leading to improved performance, reduced downtime, and an extended lifespan for infrastructure assets [24,26].

6.6. Integration of Smart Sensors

Smart sensors are becoming increasingly commonplace in structural health monitoring (SHM). These sensors collect data continuously and in realtime, allowing for constant monitoring of a building's health. They utilize advanced technologies such as fiber optics, accelerometers, and load cells to provide accurate measurements of strains, vibrations, and temperature changes [25]. The ability to customize sensors for individual projects ensures that the data collected is highly relevant and precise, which can significantly enhance safety and longevity in construction [27].

References

1. The Role of BIM in Facility Management: Boosting Efficiency.
2. Panah, R. S., & Kioumarsi, M. (2021). Application of building information modelling (BIM) in the health monitoring and maintenance process: A systematic review. *Sensors, 21*(3), 837.
3. Malekmohammadi, A., Farzadnia, N., Hajrasouliha, A., & Lyn Mayer, A. (2023). Sensing Systems in Construction and the Built Environment: Review, Prospective, and Challenges. *Sensors, 23*(24), 9632.
4. O'Shea, M., & Murphy, J. (2020). Design of a BIM integrated structural health monitoring system for a historic offshore lighthouse. *Buildings, 10*(7), 131.
5. Case studies: BIM-SHM integration - Next Industries
6. Liu, Z., Deng, Z., & Demian, P. (2018, October). Integration of Building Information Modelling (BIM) and sensor technology: a review of current developments and future outlooks. In *Proceedings of the 2nd International Conference on Computer Science and Application Engineering* (pp. 1-5).
7. Kazado, D., Kavgic, M., & Eskicioglu, R. (2019). Integrating building information modeling (BIM) and sensor technology for facility management. *Journal of Information Technology in Construction (ITcon), 24*(23), 440-458.
8. Structural Sensors – 8. Monitoring movements in structures | Sixense North ...
9. Structural sensors - Sixense
10. Types of Sensors in Construction Industry; 2024 Review
11. IoT and BIM: Transforming Facility Management into a Smarter Operation
12. Revolutionizing Maintenance with Easier, Smarter Solutions
13. Desogus, G., Quaquero, E., Rubiu, G., Gatto, G., & Perra, C. (2021). BIM and IOT sensors integration: A framework for consumption and indoor conditions data monitoring of existing buildings. *Sustainability, 13*(8), 4496.
14. Scianna, A., Gaglio, G. F., & La Guardia, M. (2022). Structure monitoring with BIM and IoT: The case study of a bridge beam model. *ISPRS International Journal of Geo-Information, 11*(3), 173.
15. Kothawade, A. S. (2024). A Case Study on BIM Integration Data Management in Construction Projects. 2024 Innovation in the Construction Industry.
16. Fernández Rodríguez, J. F., Picardo, A., Aguilar-Planet, T., Martín-Mariscal, A., & Peralta, E. (2025). Data Transfer Reliability from Building Information Modeling (BIM) to Life Cycle Assessment (LCA)—A Comparative Case Study of an Industrial Warehouse. *Sustainability, 17*(4), 1685.
17. Liu, Y., & Nayak, S. (2012). Structural health monitoring: State of the art and perspectives. *Jom, 64*(7), 789-792.
18. Leveraging BIM 6D for Optimal Facility Management - Harmony AT
19. Farrar, C. R., & Worden, K. (2007). An introduction to structural health monitoring. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 365*(1851), 303-315.
20. How Can Digital Twins Improve Operational Efficiency? Here's The Data ...
21. How BIM is Facilitating Facility Management Process? - United-BIM
22. BIM: Modernizing Building Lifecycle Management
23. Ehab, A., Mahdi, M. A., & El-Helloty, A. (2024). BIM Maintenance System with IoT Integration: Enhancing Building Performance and Facility Management. *Civil*

Engineering Journal, 10(6), 1953-1973.

24. Integrating BIM Models into Infrastructure Design: Benefits and Best ...

25. Smart Sensors for Structural Health in Construction

26. How Structural Monitoring and Assessment Tools Are Helpful?

27. Structural Health Monitoring Sensors - VackerGlobal.