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# UPGRADING THE TRADITIONAL DATABASE THROUGH BIM-BASED SHM VISION

**Daniela DOBRE[1, 2], Claudiu-Sorin DRAGOMIR[1, 3], Iolanda-Gabriela CRAIFALEANU[1, 2], Cornelia-Florentina DOBRESCU[1, 4], Emil-Sever GEORGESCU[1]**

[1]National Institute for Research and Development in Construction,
Urban Planning and Sustainable Spatial Development – URBAN-INCERC,
266 Pantelimon Road, District 2, 021652, Bucharest, Romania
[2]Technical University of Civil Engineering of Bucharest,
122-124 Lacul Tei Blvd, District 2, 020396, Bucharest, Romania
[3]University of Agronomic Sciences and Veterinary Medicine of Bucharest,
59 Mărăști Blvd, District 1, 011464, Bucharest, Romania
[4]"Dunărea de Jos" University of Galaţi, 47 Domnească Street, 800008, Galați, Romania

Corresponding author email: dobred@hotmail.com

***Abstract***

*Structural Health Monitoring (SHM) is a technology and methodology designed to assess the condition of structural systems by evaluating potential damage that may occur after an earthquake. Building Information Modeling (BIM) tools provide storage and visualization capabilities for digitally representing a building, incorporating raw data such as photographs, measurements, point clouds, and damage information. This paper presents a framework aimed at enhancing traditional databases. It integrates data collected from various sensors installed within a structure, employing post-processing techniques like finite element analysis to evaluate the health of both structural and non-structural elements. Additionally, the soil conditions are taken into account during these assessments. The collected information is then incorporated into a BIM environment featuring an improved interface that enhances connectivity between the two system architectures. This integration utilizes standardized file formats as defined by ISO standards. Developing scientific and experimental databases for building structures is an emerging trend in global research and a key component of the Romanian National Strategy for Seismic Risk Reduction. Digital building information models facilitate real-time updates and improve coordination among intervention teams following significant earthquakes.*

***Key words***: *monitoring, digital data, damage, earthquake.*

## INTRODUCTION

Structural health monitoring (SHM) is a non-destructive in-situ methodology and technology designed to assess the condition of structural systems by evaluating potential damage that may occur before or after an earthquake. It features a modular architecture that includes components related to sensors, data acquisition and transmission, data processing and control, data management, evaluation and maintenance, among others (Georgescu et al., 2010; Dragomir et al., 2019; Arif & Craifaleanu, 2023; Chacon et al., 2023; Sun et al., 2025). Any discrete or progressive changes in the structural parameters are considered potential condition indicators for damage identification.

Nowadays, at URBAN-INCERC, SHM is conducted by using the ARTeMIS Modal Pro software, which is currently in the process of implementation within an experimental project for real-time damage detection in instrumented and monitored buildings (Dragomir et al., 2019; Dragomir & Dobre, 2023). The analysis of modal and deflection shapes, along with damage detection through the identification of changes in the dynamic characteristics of a structure - using data from ambient vibrations or seismic motions - includes several important features.

These features consist of notifications when a specified control value is exceeded and warnings about potential damage to the structure, as highlighted in Figure 1. Incorporating the phenomenon of soil-structure interaction into structural analysis, either through analytical methods or real-time monitoring using sensors positioned in the freefield (near the building or in boreholes), can provide valuable insights into the structural response during an earthquake (Craifaleanu & Borcia, 2011; 2012; Craifaleanu, 2013; Craifaleanu, 2025; Dobre, 2006; Dobre et al., 2015).

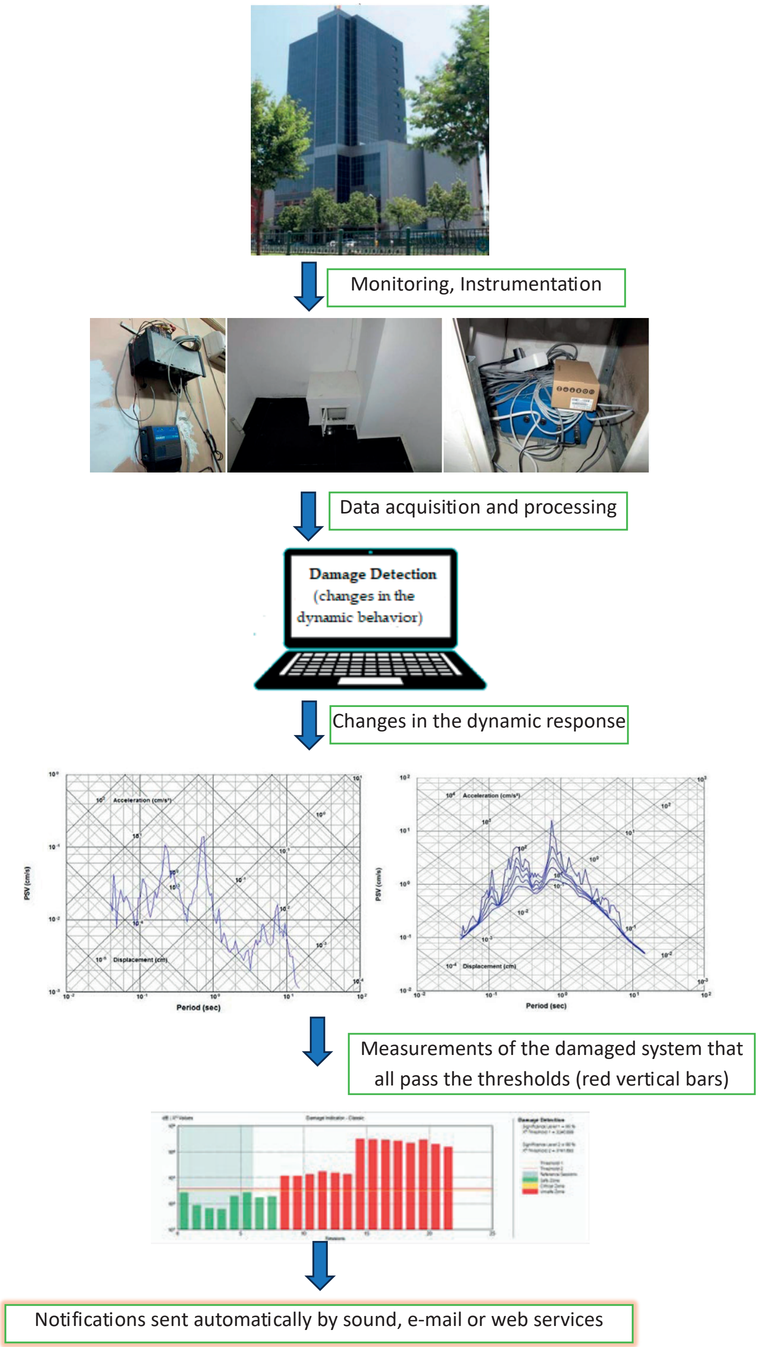


Figure 1. Implementing a remote access earthquake damage detection system within SHM for a high-rise building

The use of the finite element method in developing even simplified models of structural systems strengthens the connection between SHM and BIM by determining dynamic characteristics that evolve over time (Dragomir & Dobre, 2023). Another important factor to consider in this context is the seismic response of structures with active tuned mass dampers or any control dissipation system (Bratu et al., 2024; Paulet-Crainiceanu et al., 2024). However, the interpretation of long-term data collected from continuous monitoring SHM can be overwhelming due to the processing of an enormous amount of data. On the other hand, Building Information Modelling (BIM) tools provide storage and visualisation capabilities for digitally representing a 3D building, including lifecycle management information, with the possibility for a structural analysis and damage detection visualised in the model by assimilating the sensor data within the BIM model, that can aid the stakeholders and infrastructure owners in monitoring in real-time the state of any construction (An et al., 2015; Colucci et al., 2020; Hamdan & Scherer, 2018; Theiler et al., 2018; Singh & Sadhu, 2019; Castelli et al., 2023; Xu et al., 2023; Gragnaniello et al., 2024; Riggio & Nasir, 2024). BIM uses a static data source to assess the structure, and the sensor data can extend the application of BIM model from static to dynamic model to get the current performance of the structure (Chen et al., 2014). Within the framework established by SHM and BIM approaches, various theoretical, technical, syntactic, and semantic elements (connections between concepts and objects) aim to enhance reports generated after a major earthquake. The research directions involved in SHM with BIM and monitoring networks (seismic, but not only) show a strong correlation between key terms such as BIM, SHM, technology, damage detection, response, modal identification etc., as can be seen in Figure 2.

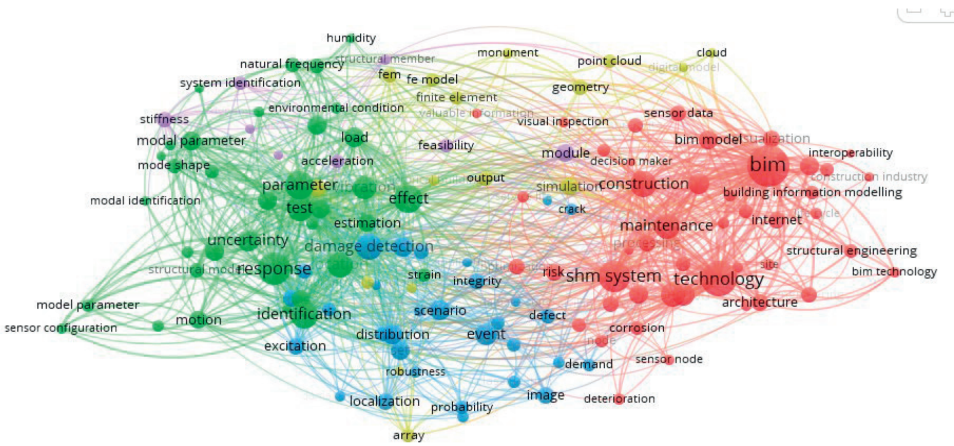


Figure 2. Frequency keywords clustering

## MATERIALS AND METHODS

### Elements of SHM and BIM as they relate to seismic monitoring

The integrated concept BIM-based SHM, i.e. to insert real-time data into the BIM model, is possible by standardizing the formats of the two approaches (formulate a standard data model to include and visualize SHM data directly to BIM models, including damage sensitive features in the object properties, data to sensor representations within the BIM model). Specific aspects of SHM and BIM are presented below, along with their technical compatibility - objectives, components, format standards, software, damage assessment.

a. Objectives:

- SHM: extracting information from structural response data collected by sensors attached to buildings;
- BIM: conventional building information (geometry, material, costs), communication,

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feedback and user-input, sharing of asset data, damage visualization;

- SHM-BIM: modelling and integrating SHM-related algorithms into IFC-based Building Information Models (IFC monitoring-related information).

b. Components:

- SHM: sensors, data acquisition system, wired/wireless connection (data transmission), communication system, data processing and storage, data analysis, damage detection, data interpretation;
- BIM: physical geometry of the building, management of vast amounts of data associated with the building, Common Data Environment (CDE) platform (all project information is stored, managed and shared).

c. Format standards

- SHM: sensor-related information - Sensor Model Language (SensorML), Semantic Sensor Network (SSN) Ontology, Systems Modeling Language (SysML), Web Ontology Language (OWL);
- BIM: Proprietary file formats (RVT, NWD, DWG), Non-Proprietary file formats (Construction operation building information exchange (COBie); Industry Foundation Classes (IFC));
- SHM-BIM: IFC Monitor to describe SHM (semantic compositions of SHM systems, network topologies, and semantic relationships between components of SHM systems and components of structural systems to be monitored), Exporting Revit SHM model to IFC, Information delivery specification (IDS) based on specific Level of Information Need (LoIN).

d. Software:

Revit and Robot Structural Analysis, REVIT and MATLAB, Excel, Autodesk, Dynamo, GIS.

e. Damage assessment:

- SHM: without any particular physical model, only data-driven approaches, but analytical models (identify the characteristics of damage progress and predict the future state); physics-based approaches, with a physical damage model and with measured data (An et al., 2015);
- BIM: plug-in for BIM environments to study the preservation of any structural element (Fernández-Mora et al., 2025; Ionita & Stoian, 2024); BIM through the Revit add-ins able to store and manage real-time data (Chen et al., 2014), developed using Revit's NET API (Application Programming Interface);
- SHM-BIM: identify and visualize the damage status of the structural and non-structural elements following a seismic event, from direct measurements by sensors installed on the building; The information processed therefore it can be inserted into fragility curves relating the performance of the element as a function of an engineering demand parameter such as the absolute acceleration or the inter-story drift ratio; information imported into modelling software working on a BIM architecture through a specific code. The procedure provides both a clear and immediate visualization of the building's health status, and its real-time sharing in the cloud (Castelli et al., 2023).

Figure 3 shows the already multidimensional relationship based on all aspects presented above between SHM and BIM.

## RESULTS AND DISCUSSIONS

### How could the traditional database be upgraded?

The main objective of enhancing the relationship between Structural Health Monitoring (SHM) and Building Information Modeling (BIM) is to evaluate how a structure performs and to detect potential damage. This is accomplished by analyzing changes in its dynamic characteristics, which include natural frequencies, damping ratios, mode shapes, inter-story drift ratios, and the modal assurance criterion.

Keeping in mind the classic components of SHM (Figure 1) and the possible multidimensional relationship between SHM-BIM (Figure 3), for a correct upgrade of the existing database, with several buildings already instrumented and/or seismically monitored, it is necessary to initially evaluate the current situation of all data formats acquired in fields such as urban planning, cadastre, design, research, signal processing, or multidisciplinary ones.

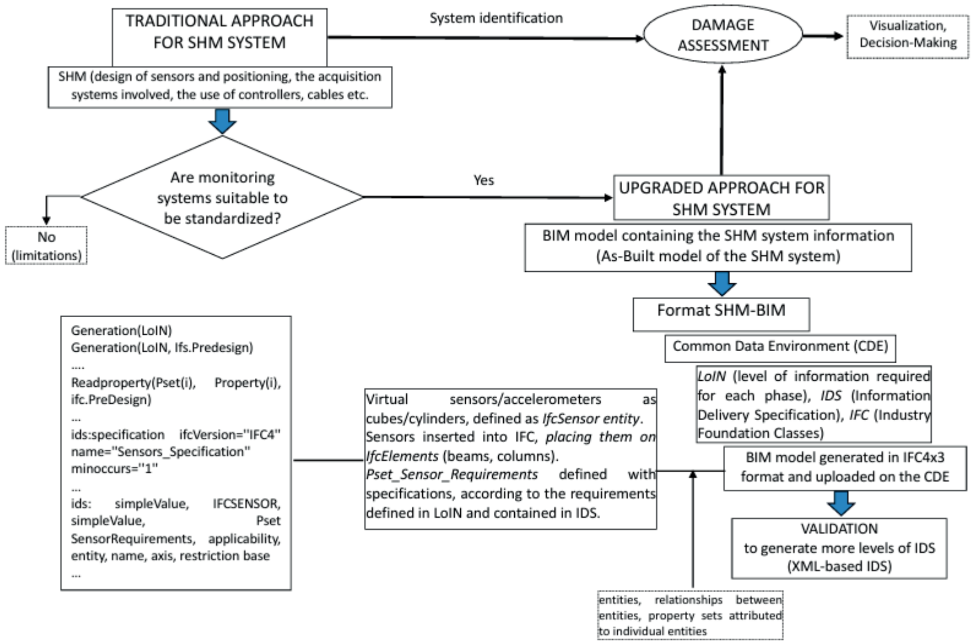


Figure 3. A multidimensional relationship SHM-BIM

The text describes the integration of Structural Health Monitoring (SHM) and Building Information Modelling (BIM) to enhance the management of building data. It emphasizes that providing accurate geospatial information and attributes about the condition of buildings is essential. By leveraging the strengths of both SHM and BIM, it is crucial to ensure compatibility of the data formats used, as this is a key factor in achieving effective real-time monitoring and modelling. Then, the compatibility of these formats with the corresponding structural software for linear and nonlinear static and dynamic analyses is considered. In the next stage, a data management system for storage, retrieval and sharing of extremely large measurement data sets constantly acquired from SHM systems and the creation of web interfaces are required. The options for a database are relational (MySQL)/non-relational (NoSQL), with adaptability, high traffic capacity and open-source.

An integrative concept for the digital analysis of seismic monitoring data is currently being developed at INCD URBAN-INCERC. This initiative aims to cover a large area of the national territory and its built environment, facilitating the rapid identification of the destructive potential of earthquakes. The effectiveness of this concept is evident in its ability to characterize seismic motion and evaluate the structural system of the monitored building. This includes real-time visualization, processing, and analysis of seismic recordings using SeisComP software, as well as the graphical representation of shake maps that incorporate attenuation laws. SeisComP has its own data storage and archiving system, compatible with SeedLink (an international standard in the field). Data archiving is done through SDS (SeisComP Data Structure), in which the archiving format is compatible with SeedLink. The seismic data storage structure follows pre-established hierarchical levels, adapted to specific needs. Certain essential BIM elements are currently absent, which limits the provision of crucial technical information related to buildings, utility networks, ground conditions, acoustic parameters, energy consumption, various costs, and solutions for data access, storage, archiving, data security, software updates, AI and machine learning integration, as well as backup and recovery tools. As part of an experimental program focused on seismic monitoring of buildings, data is generated in a standardized format for several purposes. This includes finite element modelling, static and dynamic load testing, enhancement of existing structural health monitoring (SHM) systems, building information modelling (BIM), and supporting both national and international advancements in this field (Guide on the management and monitoring of information generated in the BIM system; EN ISO 19650).

## CONCLUSIONS

The behaviour of structural systems of buildings under dynamic actions and the detection of damage shortly after their occurrence represent important technical aspects and are, to a certain extent, obtained rapidly through monitoring, non-destructive testing. The SHM-BIM approach offers a significant advantage by enabling the definition and modelling of the pre-earthquake structural system in a compatible digital format. This aligns with established regulations for structural analysis and allows for results to be presented in the same format. Additionally, it facilitates real-time damage assessment, utilizing fragility curves as indicators of probabilistic damage or real-time identification methods based on frequency analysis for damage detection. It is also beneficial to incorporate elements related to the architecture and acoustics of buildings and installations (Zaharia, 2010; Zaharia & Voloaca, 2023), or integrating information from requirements of 3D-printing applications for the field of constructions, current technologies, the advantages of 3D printed buildings/houses with seismic/ambient vibration monitoring possibilities (Vitalie et al., 2020).

The conceptual methods and data gathered through seismic monitoring are essential for a database directly associated with seismic vulnerability. The development of scientific and experimental databases for building stock is an emerging approach in current global research and serves as a fundamental component of the Romanian National Strategy for Seismic Risk Reduction. Digital building information models enable real-time updates and enhance coordination among intervention teams after significant earthquakes.

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