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HBIM Applied to Historic Transport Infrastructures: A Systematic Literature Review

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Abstract. Extreme weather events have intensified the challenges of preserving historic heritage, adding to the complexities inherent in the characterization of materials and the structural modeling of centuries-old constructions. This issue is a recurring theme in international discussions on structural engineering. Although Historic Building Information Modeling (HBIM) is a widely adopted methodology to support the maintenance and conservation of historic buildings, its application in the field of historic infrastructure—such as bridges and viaducts within transportation systems—remains limited. In light of this, the present study aims to investigate the existing literature and key application studies of HBIM for transportation infrastructure through a systematic literature review combined with the snowballing technique.

Keywords: HBIM, Historic Heritage, Transport Infrastructure, Literature Review.

1 Introduction

Historic transportation infrastructures, such as bridges and railways, are significant structures that not only preserve the past but also connect locations. In fact, according to Salah et al. (2024), these infrastructures are important to urban development since they facilitate the movement of people and resources. Their conservation is, thus, relevant for technical adaptation, economic matters, and social purpose. UNESCO has already emphasized that the preservation of such site is a vital part of humanity`s cultural legacy, possessing historical and educational value.

In a world that prioritizes new technologies, however, focusing on historical structures can be perceived as counterintuitive to progress. Xu (2023) noted that, unlike architectural heritage, infrastructural heritage receives limited recognition, rendering it vulnerable to neglect and degradation. Extreme climate events coupled inadequate monitoring are examples of deterioration factors that accelerate the idea of giving historical structures up and dedicating to new structures.

In this context, the application of Historic Building Information Modeling (HBIM) methodology presents a promising solution for improved monitoring and management, in a way that connect the past with the new technologies. Despite its potential, HBIM implementation can be an exhaustive challenge due to the inherent complexity of these structures that usually lack documentation. Therefore, on-site surveys may be required to collect the geometrical data necessary for HBIM processes and the creation of a digital shared model. Furthermore, HBIM can be utilized to define project phases, damage mapping, and organize maintenance interventions (León-Robles, 2019).

The present study investigated HBIM literature to transportation infrastructures, aiming to understanding its current barriers and opportunities.

2 Methodology

To understand the state of the art on HBIM applied to transportation infrastructures, a systematic literature review (SLR) was conducted. This is a recognized review methodology that provides a replicale and impartial process for identifying relevant academic studies. The five-step framework, as proposed by Tranfield et al. (2002), was adopted as following: (a) formulating the research question; (b) locating relevant studies; (c) selecting and evaluating studies; (d) analyzing and synthesizing findings; and (e) reporting the results and answering the research question.

To guide this SLR, the following research question was formulated.

RQ: *What are the current findings and primary areas of focus within academic research regarding the application of HBIM to historic transportation infrastructures?*

The next step was locating the relevant studies. So, the SCOPUS database was selected to carry out the search using the following search string:

> *(TITLE-ABS-KEY(HBIM bridges) OR TITLE-ABS-KEY(HBIM bridges railways) OR TITLE-ABS-KEY(HBIM infrastructures bridges) OR TITLE-ABS-KEY(HBIM infrastructures)) AND (LIMIT-TO(EXACTKEYWORD, "Hbim") OR LIMIT-TO(EXACTKEYWORD, "Historic Preservation") OR LIMIT-TO(EXACTKEYWORD, "Building Information Modelling"))*

The initial query yielded only 46 documents, which was considered an insufficient number for a comprehensive literature review. Therefore, the search was expanded to Google Scholar using the same terms. To identify any relevant studies missed by these searches, a snowballing analysis was also conducted using the ConnectedPapers platform in July 2025. The snowballing technique consisted of tracking citations and cross-references from the found publications by the SLR to uncover further relevant literature.

From the final sample of studies captured by the SLR with snowballing, it was possible to understand some insights that may be interesting to map the studies and research areas. For instance, the geographical distribution revealed a predominance of studies from Europe (Figure 1), with Spain emerging as the country with the highest number of works on this topic. This demonstrates the greater strength of Western Europe in terms of investment in the documentation and conservation of historical infrastructure. In contrast, only one study was identified from Latin America. This insight highlighted the importance of studying this topic in Latin America which has several historic transportation infrastructures dated from Spanish and Portuguese colonization. It is also necessary to highlight the advances made in the studies on this topic. In the last years, there has been observed a steady growth in the amount of research, which has lad to advances in the field (Figure 2). However, it is worth that, although the topic is ample, in terms of its scope and applications in different contexts, the diversity of approaches and studies is still limited, as will be seen throughout this research.

Following the SLR methodology, the next step was the selection and evaluation of studies based on a screening process, which consisted of reviewing the titles and abstracts. The inclusion/exclusion criteria were defined as described in Table 1. Studies that did not clearly meet the inclusion criteria were excluded. This filtering process narrowed the selection to a final sample of 19 studies, which was fully read in the next SLR step.

Table 1. Selection criteria adopted in the SLR methodology.

Selection Criteria	
Inclusion	Exclusion
Studies specifically focused on the use of HBIM in historical transport infrastructures	Studies involving the application of HBIM in buildings
Studies involving real case studies, literature reviews, or hypothetical studies	Studies not registered with a DOI
Peer-reviewed journal articles, conference papers, or book chapters	Studies focused on infrastructure BIM, without references to HBIM

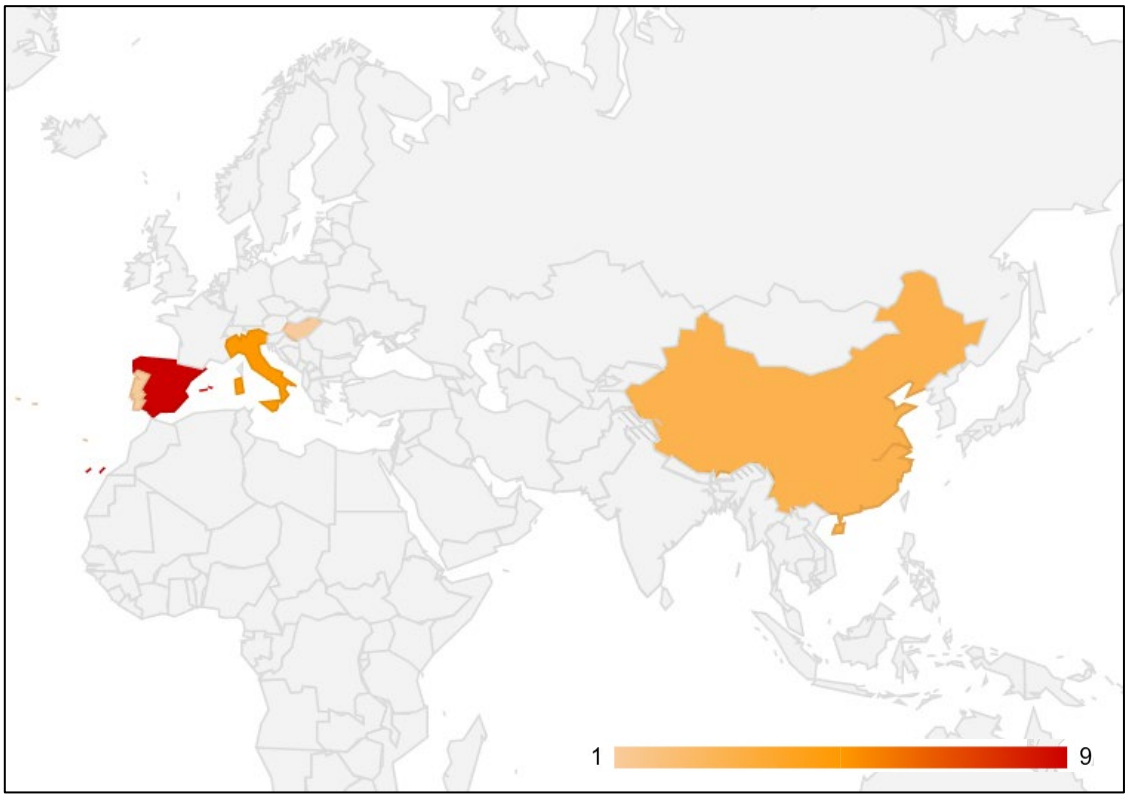


Figure 1. Distribution of articles according to the number of publications in each country

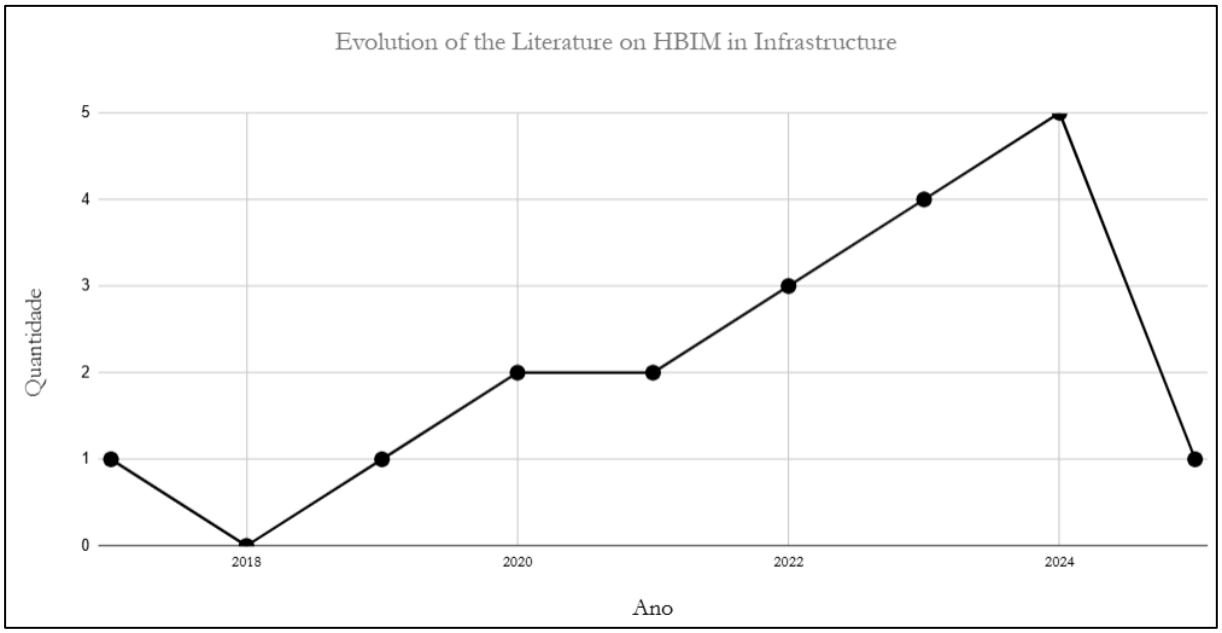


Figure 2. Distribution of articles by year of publication

3 Results and discussion

From the complete reading of the final sample of publications collected by SLR and snowballing analysis, the literature revealed key trends, applications, and challenges in the use of HBIM for transportation

infrastructures. The findings are synthesized and discussed below.

3.1 About data acquisition and modeling techniques

Most of studies showed that the most effective method for implementing HBIM is a *Scan-to-BIM approach*. This process uses laser scanning and/or photogrammetry to create a detailed point cloud point model, that is usually a raw data that can be processed and refined to be used as a basis for modeling procedures. For instance, Cabaleiro (2020) used aerial photogrammetry via unmanned aerial vehicles for the modeling of the Lapela Bridge, while Léon-Robles (2019) adopted terrestrial laser scanning for the Izbor Stone Bridge model. Beyond the digital modeling, the importance of the documentation and management of such heritage infrastructures are highlighted by Donato (2017), Di Donato (2022), and Xu (2023).

3.2 About structural analysis and digital twins

Also, the literature showed a strong trend toward using HBIM for structural analysis. In 2017, Donato (2017) has already detailed the methodological and operational challenges of applying HBIM to historic infrastructure, while subsequent studies have demonstrated the benefits from the creation of digital documentation that supports intervention planning to develop integrated models for structural health monitoring (SHM). Casimiro-Bernárdez (2023), for example, integrated structural analysis into the HBIM model of the Twenty Eyes aqueduct.

Cruz (2024) advanced this approach by proposing a separation of models: a detailed model of visualization and a dedicated analytical model for structural simulations. It is worth pointing out that the structural dedicated model was developed using Finite Element Method (FEM) analysis and so, the stress mapping and critical structural results were linked back to the main HBIM model. The HBIM model worked, thus, as a central reference that sends and receives information from the structural analysis. Similarly, Chacon (2024) observed that HBIM model lacks often a proper material characterization for structural analysis and, thus, focused her/his study on detailing the material in masonry bridges to better integrate the structural model with HBIM model.

Note that HBIM model does not contain all information necessary for the structural analysis and its detailing occurs in the specific platform designated. Here, the present study studied the structural field, but for energy fields, similarly the information needed for energetic simulations are modeled usually in specific platforms.

Furthermore, Bouzas (2022) studied the use of HBIM to create a digital twin for the SHM of the Barqueiro Bridge in Spain. The Scan-to-BIM model was integrated using ANSYS, a recognized FEM software, to simulate loadings, dynamic analysis, and deformations. The FEM model results were validated using on-site measurements and, for that reason, it can be understood as digital twin – the information is bidirectional from the digital models to the physical world.

3.3 About other technologies

A continuous effort to enhance the HBIM methodology by integrating it with other technologies is evident. Di Donato (2022) combined HBIM with procedural modeling using Dynamo, a visual programming language. This was used to automate the generation of repetitive elements like rolled profiles, bolts, and trusses, using a combination of historical drawings and point cloud measurements. This application introduces a new dimension to HBIM, increasing efficiency and reducing modeling time, though it requires caution and manual oversight for geometrically complex or highly degraded structures.

Integration with Geographic Information Systems (GIS) is another significant area of research. Xu and Garamone (2023) merged HBIM with GIS to manage the assets of the Chinese Eastern Railway, linking 3D models of tunnels, bridges, and stations to cartographic databases. This created a comprehensive model enabling spatial analysis and a broader territorial understanding. Later, Xu and Scaioni (2024) extended this by integrating HBIM with Historical GIS (HGIS) to digitally reconstruct vanished metal bridges from the same railway. García-Valldecabres (2023) also leveraged this integration to create virtual itineraries for the Historic Center of Valencia, Spain.

3.4 About the project type

The applicability of HBIM has been demonstrated across a wide spectrum of infrastructure types, confirming that the methodology can be adapted to the unique particularities of different structures. The reviewed literature includes case studies:

Table 2. Types of infrastructures observed in the literature.

Tipology	Publications
Metallic and masonry bridges	(Cabaleiro, 2020; Bouzas, 2022; Di Donato, 2022; León-Robles, 2019; Cruz, 2024; Conti, 2020; Donato, 2017; Chacon, 2024)
Historic railway networks	(Xu & Garamone, 2023; Xu & Scaioni, 2024)
Hydraulic infrastructures	(Aqueducts and Dams): (Casimiro-Bernárdez, 2023; Martínez-Carricondo, 2021)
Urban infrastructures	(Polaina et al., 2022; Salah et al., 2024)

3.5 Mapped challenges and limitations

Despite its successes, researchers identified several recurring challenges on HBIM applied to transportation infrastructures, as described next. The most common obstacle is the geometric complexity of historic structures, which often feature curved, irregular, and deteriorated forms. Cabaleiro (2020) highlighted the difficulty of creating adequate parametric objects, which can limit the quality of the final digital model.

Also, regarding interoperability issues, when integrating HBIM with other technologies, a lack of seamless interoperability is a major hurdle. As previously mentioned, Xu (2023) reported a significant loss of semantic metadata when converting a model from IFC to CityGML, requiring rework in the GIS environment. Similarly, Bouzas (2022) noted that exporting models to ANSYS required geometric simplifications and manual adjustments to meet calculation criteria. Esses desafios reforçam o conflito recorrente entre a precisão geométrica e a compatibilidade entre plataformas, levando à criação de soluções híbridas que conciliam modelos detalhados para visualização e versões simplificadas para análise estrutural, como destacado por diversos autores.

It is also important to highlight the lack of historical libraries. Donato (2017) emphasized the absence of parametric object catalogs compatible with historical construction standards, pointing to a general lack of historical elements in modern digital libraries. In fact, he high complexity of information within HBIM models presents a management challenge. Conti (2020) and Cruz (2024) highlighted the need to develop custom classification systems and information hierarchies to manage data effectively, sometimes requiring the separation of models into different layers of information for different applications.

Finally, Bouzas (2022) also pointed to logistical challenges associated with maintaining monitoring devices in external, often harsh, environments. Overall, it can be seen that the challenges encountered are interconnected, which highlights the need for more established and better integrated methodological approaches, which would considerably improve the applicability of HBIM in historic infrastructures.

4 Conclusions

Based on the publications found in SLR, there are some key points to highlight. First, the authors noted that it is important to create a unified theory about this topic, democratizing the lessons learned and creating an educational framework for future studies. The creation of courses and training in the universities could increase the accessibility and dissemination of HBIM, thereby expanding the technical capacity of researchers and professionals in the field. Second, the literature showed that it is necessary to develop parametric libraries for HBIM, in which typical construction elements from various historical periods could be used in the digital modeling process. Also, it is important that these libraries could be hosted on collaborative and open-access platforms, to be

aligned with the first point. Third, the interoperability issue must be addressed in future works, according to the studies found on SLR. The adoption of open formats, such as IFC, may be a solution that are also aligned with the previous concluding points. Fourth, future work should also focus on leveraging HBIM for real-time structural health monitoring. As pointed by some studies, the integration with IoT technology and the development of custom scripts are needed.

In summary, strengthening the HBIM methodology for historic infrastructures depends not only on technological advancement but also on a commitment to four foundational pillars: democratization of tools and knowledge, synergy among institutions, standardization of protocols, and training for the next generation of specialists.

Finally, it is necessary to emphasize the importance of expand the geographical scope of literature, given that the predominance of European studies limits understanding of different constructive contexts, such as those in Latin America, which present particular challenges and opportunities for the development of HBIM.

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