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H-BIM FOR THE CONSERVATION OF WOODEN STRUCTURES: A KNOWLEDGE-BASED PROTOCOL INTEGRATING GEOMETRY, HISTORY AND STRUCTURE

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Abstract

This study investigates the potential of Heritage Building Information Modeling (H-BIM) as a framework for systematically gathering and analyzing data on wooden structures in historic buildings. The objective is to enhance the understanding of structural implications arising from historical, construction, and conservation-related factors. A set of customized properties is introduced to facilitate the acquisition of key data, establishing predefined relationships to enable effective correlation between essential diagnostic aspects, including geometry, historical contents, construction characteristics, wood defects, and decay processes. The influence of these factors on structural behavior is emphasized to ensure a comprehensive assessment that integrates the entire interdisciplinary knowledge. The proposed methodology is applied to a case study involving the wooden trusses of a historic building in Parma. Therefore, the main achievement of this paper is to test the efficacy of H-BIM in receiving spatially localized and interdisciplinary information for a critical structural analysis.

Keywords

H-BIM, wooden structures, guided knowledge, structural assessment, conservation

1. *Introduction*

In recent years, the application of Building Information Modeling (BIM) to the field of cultural heritage – commonly referred to as Historic or Heritage BIM (H-BIM) – has demonstrated significant potential in supporting conservation processes through the systematic management of spatially located data. Indeed, these digital models enable the association of non-geometric information with three-dimensional representations, offering a more faithful and integrated view of the built environment compared to traditional two-dimensional documentation. However, the use of BIM for historic structures remains a complex task, primarily due to the limitations of software platforms and data exchange formats originally developed for contemporary buildings. These systems often lack flexibility, semantics, object libraries and specific data framework required to appropriately represent historic materials and construction systems (Bruno & Roncella, 2019).

Moreover, while in applications to new constructions BIM serves as an effective container of interdisciplinary data, the information models of historic buildings still struggle to achieve this goal. Such limitations become particularly evident in the management of analysis and conservation activities on wooden structural elements. Indeed, timber components present a multifaceted challenge, since construction details, historical stratification, material deterioration, and structural behavior are deeply interdependent. Properly addressing these aspects requires a comprehensive and coordinated approach. In this regard, the Italian standard UNI 11119:2004 emphasizes the importance of decay and defects of timber observed through visual inspections to define the mechanical properties of wooden components of historic buildings.

Despite this, conservation activities on architectural heritage are frequently marked by a fragmentation of responsibilities and perspectives. Architects and conservators tend to focus on historical analysis and construction or decay aspects, while structural engineers prioritize structural safety. The use of distinct methodologies, tools, and representation formats across these disciplines often hinders effective integration. As a result, structural assessments may be based on overly simplified models that fail to account for the positive contribution of significant construction details or of a good state of preservation, potentially leading to invasive works that conflict with the principle of minimal intervention.

In this framework, information models can play a crucial role not only in storing data, but also in structuring the knowledge acquisition process. An H-BIM model, when properly designed, can act as an interpretive tool that supports the systematic collection, classification, and correlation of diverse data types. The model becomes a key reference for subsequent analysis and design decisions, and its accuracy and representativeness directly affect the reliability of proposed interventions.

This contribution presents a methodology aimed at enhancing the understanding of historic timber structures through the development of a structured information model. The approach includes the semantic classification of elements, their geometric modeling and, above all, the definition of specific properties, grouped by thematic domains, with the goal of guiding the survey and assessment process in an integrated manner. The proposed workflow is applied to a case study: the 18th-century trusses covering a portion of a palace in the historic center of Parma (Italy). Through this case, the study illustrates a generalizable strategy for managing the conservation of wooden structures via H-BIM, promoting a unified and interdisciplinary approach to analysis and intervention planning.

2. *Heritage BIM for Wooden Structures: An Overview of Existing Research*

In the field of Historic Building Information Modeling (H-BIM), managing information related to wooden construction elements deserves particular attention due to the unique characteristics of the material and the structural implications of its geometry and decay. Santos, Sousa, Cabaleiro, & Branco (2023) present key findings on the development of H-BIM models for wooden structures, focusing on both geometric aspects (including metric data acquisition) and information management. Their work encompasses historical construction data, visual inspections for damage assessment, and diagnostic investigations, which are particularly valuable for determining the mechanical properties of materials. Ultimately, these insights support the export of models for structural analysis.

Most studies have primarily focused on geometric modeling, particularly on the Scan-to-BIM process, which seeks to incorporate the irregularities of wooden elements into 3D models, sometimes through automated procedures. These irregularities, such as deformations or reductions in cross-section, may originate during the construction phase or develop over time due to degradation, and are captured through precise instrumental surveys (Cabaleiro, Hermida, Riveiro, & Caamaño, 2017; Özkan, Pfeifer, & Hochreiner, 2024; Prati, Guardigli, & Mochi, 2021). The complexity of joints and details, often further complicated by interventions carried out over time, is represented using different modeling strategies: direct, parametric, generative or semi-automatic (Mao, Lu, Xiao, Lai, & Huang, 2024; Panayiotou & Kontovourkis, 2024; Özkan, Lavric, Hochreiner, & Pfeifer, 2025). The modeling phase is preceded by the hierarchical and semantic classification of structural elements (Z. Wang, Lu, Hu, Wu, Tan, Khaliq, Al Mamun, & Zhang 2024).

Other studies have proposed specific library objects. Although geometrically simplified, these models assist in representing repetitive elements, helping to compensate for the lack of parametric objects for wooden structural components in historic buildings, such as trusses and timber floors (Oreni, Brumana, Georgopoulos, & Cuca, 2013).

Less common, yet more aligned with the approach presented in this paper, are studies that emphasize structuring non-geometric data. In (Mol, Cabaleiro, Sousa, & Branco, 2020), the geometric modeling is simplified by assigning a regular cross-section to the wooden beams, derived from the average dimensions calculated from the point cloud data. The specially developed properties include links that provide access to various data types: point clouds (from two survey campaigns conducted in different years to assess degradation progress through cloud comparison), photographic surveys, diagnostic test reports and graphs. In (Santos, Cabaleiro, Sousa, & Branco, 2022), considering that degradation in wood (be it rot or insect attack) primarily results in the destruction of the outer layer of the element, two different models are proposed: the first with the "apparent" section, obtained from the point cloud; the second with the "resistant" section, reduced proportionally according to resistographic test results, and later exported for structural analysis.

The research presented in (Massafra, Prati, Predari, & Gulli, 2020) and related to a roof with timber trusses aims to evaluate the modifications and deformations that occurred over time by comparing the model representing the current state (obtained from laser scanning surveys) with the ideal model that reconstructs the hypothetical initial configuration. The analytical model is generated automatically by an algorithm that extracts the axes of the beams and is enriched within the BIM environment with information such as mechanical properties, constraints, and loads, which are then transferred to structural analysis software. The transition to structural analysis is also discussed in (Bassier, Hadjidemetriou, Vergauwen, Van Roy, & Verstrynge, 2016), where timber elements are modeled with high metric accuracy, with particular focus on translating wooden connections into structural constraints.

The model presented in (J. Wang, You, Qi, & Yang, 2022) incorporates structural monitoring data for wooden elements through the development of a dedicated platform. Alarm thresholds corresponding to various levels of alert are proposed and visualized in the model by automatically assigning colors to the objects representing the sensors.

In (Celli & Ottoni, 2023), a detailed information apparatus specific to wooden structures is proposed to support the process of preventive planned conservation. This includes general data, such as wood type and dating, as well as geometric information, mechanical properties and state of preservation. An additional group of properties pertains to the "Classification by Resistance" which, according to the UNI 11119:2004 standard for Cultural Heritage, evaluates material strength based on the presence or absence of defects. Diagnostic investigation results are also included as attributes of the objects corresponding to the wooden elements. The final section of the proposed data structure calculates a "Priority Index", which combines the historical-construction value of the object with its damage and risk conditions, providing a key parameter for planning conservation interventions.

Very interesting in this regard is the research presented in (Bruno & De Fino, 2021), aimed at incorporating into H-BIM information useful for "Classification by Resistance" of wood, still in accordance with UNI 11119. In particular, VPL (Visual Programming Language) is used to achieve automated data processing. The goal, in the cited article as well as in the present contribution, is to transpose "analogical" and coded (thanks to regulations) practices into "digital" routines.

In (Henek & Venkrbec, 2017), a summary evaluation of the state of conservation of the trusses is visualized in the model by assigning colors to the elements. Finally, in (Santini, Borghese, & Baggio, 2023), the H-BIM model is conceived as a support for choosing among various design alternatives for strengthening historic wooden structures. As the authors point out, these structures are often completely replaced, due to a lack of maintenance. However, the breakdown in communication between conservation and structural aspects also hinders proper evaluation and therefore increases the risk of replacement. The aim here is to mitigate this issue through the use of information modeling.

3. *Proposal for an Information Framework for Wooden Structures*

As previously mentioned, the objective of the present study is to propose an information framework specifically for wooden components with structural function found in historic buildings. This framework is intended to serve as a "guide" for collecting data on geometry, construction details, and deterioration, while also aiding in the understanding of their structural implications. Therefore, customized properties are proposed to be associated with objects in H-BIM models corresponding to timber structures, facilitating the capture of various aspects essential for an accurate diagnosis (Cruz, Yeomans, Tsakanika, Macchioni, Jorissen, Touza, Mannucci & Lourenço, 2014). In this way, the information system guides the surveyor on what to observe and incorporate into the model.

The proposed workflow is shown in Fig. 1. Defining the entities that constitute the model is the initial step. Entities need to be defined both geometrically and semantically. Regarding geometric modeling, a simplified approach using parametric objects is preferred, as further explained. In order to semantically define the timber components, a specific classification called

"Wooden Structural Element" is introduced and incorporated into the system. This allows custom properties to be associated with the model objects classified as "Wooden structural element"[1].

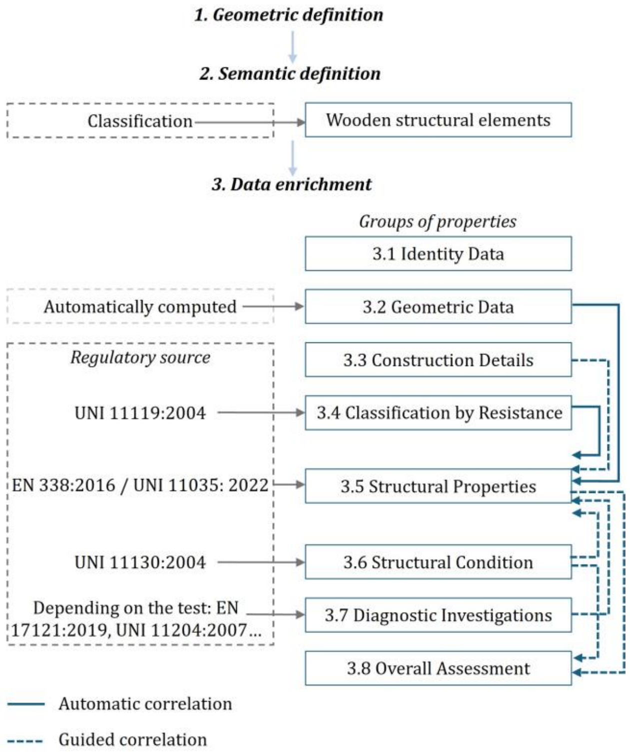

Fig. 1: Diagram of the methodological flow proposed for informative representation of wooden structural elements.

Most of these custom properties are structured to accept only predefined values within a specified domain, utilizing single- or multiple-choice drop-down menus. This approach ensures that the tool not only suggests the aspect to be detected but also provides the possible responses, which are sometimes aligned with regulatory standards[2] (Riggio, D'Ayala, Parisi, &Tardini, 2018). A closed vocabulary of possible answers ensures adherence to a standardized nomenclature[3], promoting the semantic interoperability of the proposed system. Furthermore, the use of defined domains facilitates the establishment of correlations between different properties, as well as efficient search queries within the database, which constitutes the information model. In other cases, the predefined answers are scores indicating the severity of the phenomenon, contributing to the overall assessment.

Other properties, however, are structured as free-entry fields, allowing for the manual input of text strings or numerical values. This is typically the case for qualitative assessments or detailed notes that provide further context on other parameters. Subsequently, correlations are established between different types of information, primarily between construction-conservation aspects and structural properties. It is important to note that, in the case of wood – more so than with other materials – Italian regulations, particularly those concerning Cultural Heritage, provide standardized classification procedures and correlations between construction and structural aspects. This makes wood an ideal pilot case for developing a specific information framework for the characterization and diagnosis of structural elements in historic buildings. In cases where the regulations allow for an "automated" correlation, the properties receiving such correlations are defined through logical operations, which can be managed directly within the BIM software[4]. Alternatively, some "Guided" correlations, on the other hand, are suggested during the data entry process, attempting to clarify the structural implications of the various issues[5].

To facilitate information management, the proposed customized properties are organized into groups belonging to different disciplinary domains: mainly structural analysis and heritage conservation (Groups of properties in Fig. 1).

The following sections 3.1-3.8 describe each group of information in detail.

3.1 Identity data

The first group pertains to the "Identity Data", which include the relevant information for identifying each individual wooden element (Tab. 1). Specifically, the first field in this group regards the role of the element within the structural system, allowing the user to specify whether it is a beam, joist, truss rafter, king-post, etc. The next

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[1] The model is developed in Archicad BIM authoring software. Therefore, information modeling employs the software's own tools and logic.

[2] As explained subsequently, this is the case of the properties regarding the classification according to UNI 11119:2004, or the mechanical characteristics of the material, derived from EN 338:2016.

[3] As for the nomenclature regarding decay phenomena, for which in Italian there is reference to the standard UNI 11130:2004.

[4] This process can be also streamlined by linking the element schedule containing all information associated to the model entities with an Excel spreadsheet.

[5] These suggested "guided" correlations are displayed in the description of the various properties in Archicad.

entry concerns the wood species, which, as further detailed below, is a key data for determining mechanical properties of the element. Following this, the hypothesized age and the date of the last maintenance intervention (when known) are recorded, along with any identifiable past interventions or reinforcement elements.

Tab. 1: "Identity data" property group. When the property assumes only predefined values, these are specified. No entry is given in the table for free-entry fields.

Property	Options
Type of element	Beam, joist, rafter, king-post, etc.
Wood species	Oak, chestnut, pine, fir, poplar, larch, etc.
Age of the element	-
Past interventions	-
Last maintenance work	-

3.2 Geometric data

The objects of the model are geometrically simplified, undeformed and regularized compared to the reality. The type of section is specified (circular, rectangular, chamfered, etc); the main dimensions of the model's objects are automatically calculated by the software and included in this group (Tab. 2).

Tab. 2: "Geometric data" property group.

Property	Options
Section type	Rectangular, circular, semicircular, with chamfers, etc.
Height [cm]	-
Width [cm]	-
Length [cm]	-

3.3 Construction Details

The next group pertains to the "Construction Details", which include both the embedding of the beam into the masonry and the connections between different wooden structural elements (Fig. 2).

Construction details can be simplified in the geometric model, yet transposing the fundamental data as associated information. As well known, the type of connection is particularly important, as it influences the structural constraint to be applied in the structural modeling process. The description of constraint is suggested and then

Fig. 2: Examples of different kinds of connections between rafters and tie-beam of trusses and different configurations of king post.

included in the group related to structural properties, but needs validation by the operator.

Specifically, a property is proposed for each of the following aspects (Tab. 3): the depth of the bearing on the wall, which affects the distribution of stresses transferred from the wooden structure to the masonry; the potential presence of sleeper beams (*dormienti*), masonry or wooden corbels (*mensole*), anchor plates (*capochiavi*) securing the beam to the vertical wall; the presence and positioning of metal brackets; the geometry of the wooden joints, which also impacts the transmission of stresses; and whether the beam consists of multiple wooden elements. Other properties are specific to trusses and influence the selection of the structural scheme to be considered (Aveta, 2013).

For example, possible configurations of the king post are classified (resting on the tie beam, elevated, or connected with a bracket), as well as the characteristics of other connections (bearing of the purlins on the trusses, connection between the king post and the rafters, details of the diagonal braces, etc.)(Fig. 2).

Tab. 3: “Construction Details” property group.

Property	Options
Depth of bearing [cm]	-
Dormienti	Both sides, one side, none
Corbels	In masonry, in wood, none
Anchor plates	Both sides, one side, none
Metal brackets or plates	None, between rafter and tie-beam, between beam and corbel, etc.
Composite beam	T/F
Geometry of wooden joint	Simple or double tooth, mortise and tenon, etc.
For trusses King post configuration	resting on the tie-beam, elevated, connected with bracket

3.4 Classification by Resistance

The central aspect of the correlation between construction and structural issues lies within the “Classification by Resistance” group.

This classification enables the mapping of wood defects based on a visual on-site assessment. Defects such as chamfers, knots, presence of shrinkage cracks and grain inclination (Tampone, 2000) are considered, and decrease the mechanical properties of the element (Fig. 3). The fields of this group allow to select from several options corresponding to the thresholds outlined in the UNI 11119:2004 standard (Tab. 4). Guidelines for proper compilation are provided in the H-BIM model. In this way, once selected the correct option, the wood element’s class is automatically determined according to the standard, which defines three categories (class I, II, III), where Class I indicates wood with minimal defects and, therefore, greater strength.

Fig. 3: Examples of defects and criticalities about the state of conservation of wood. From above: knots, shrinkage cracks, inflection, loss of efficacy of connections, reduction in section.

Tab. 4: “Classification by resistance” property group.

Property	Options
Regulation	UNI 11119:2004
Chamfers	<1/8, <1/5, <1/3
Crack, frost damage, ring shake (*cipollatura*)	T/F

Single knots	<1/5 (50 mm), <1/3 (70 mm), <1/2
Group of knots	<2/5, <2/3, <3/4
Grain inclination- radial	<7%, <12%, <20%
Grain inclination-tangential	<10%, <20%, <33%
Shrinkage cracks	Passing, non-passing, none
Class	I,II,III

3.5 Structural Properties

The "Classification by Resistance" is directly integrated to the group related to "Structural Properties"[6]. This group encompasses all the information necessary for structural assessment.

Based on the wood species and its assigned category, the appropriate "Strength Class" is selected. As a result, the mechanical properties are determined in accordance with this classification and to EN 338:2016 standard. The strength can be adjusted based on the qualitative results obtained from the investigations (Feio & Machado, 2015), such as resistographic tests or moisture content measurements. This adjustment is not automatic; however, if the tests identify degraded wood, a lower strength class may be selected, as outlined in the flowchart in Fig. 1.

The same group also includes data related to both permanent (structural and non-structural) and imposed loads, which are crucial for the structural analysis of the element. As illustrated in Section 3.3, the type of structural constraint is recorded in this group and suggested based on specific construction details. This information must be carefully considered during the export process for structural analysis. Thus, the information model functions as a repository for interdisciplinary data, serving various professionals involved in the restoration project.

Structural analysis is independent from the information model[7]. However, summary results, such as verification rates for bending, shear or stability, can be incorporated into the model to track all assessments made on the structures.

3.6 Structural Condition

A further group contains all the information regarding the "Structural Condition", specifically those types of degradation (prevalent in wooden elements) that impair the performance of the structural element (Tab. 5).

These include rotting, insect attack (whether active or past)[8], inflection, lateral deflection (with data recorded in cm, measuring the deviation from the axis), local reductions in section, cracks and the loss of efficacy of connections. When possible, the severity of degradation is assessed on a scale from 0 (absent) to 5 (very severe), allowing for the derivation of a synthetic parameter that indexes the element's damage state (Fig. 4). This can be calculated as an average of the severities assigned to the different types of degradation, while also accounting for numerical values associated with the measured deformation.

According to this approach, the decay information is treated as a property of the entire modeled object. While this method enables quick diagnosis and effective correlation between different data, it has the limitation of not allowing precise localization of the phenomenon, which is generalized across the whole element, as noted by (Delpozzo, Treccani, Appolonia, Adami, & Scala, 2022). To address this limitation, in the present study it is proposed to include a property related to the "Spread" of the damage. Indeed, the decay can be localized, diffuse or limited to the heads, as it is often the case in wooden beams. Additionally, detailed degradation surveys are linked. Given the

Fig. 4: Different levels of severity of decay. From left to right: level 1-2, level 3, level 4-5, decay limited to beam head.

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[6] Actually, UNI 11119:2004 provides the allowable stresses, which must then be "translated" into characteristic values.

[7] It would be also possible to work with Excel files that are automatically linked to object properties.

[8] The decay phenomena are classified, when possible, according to the definition given by UNI 11130:2004.

current development stage of BIM authoring software, models cannot yet fully replace traditional representations.

These will likely remain complementary to information models, as they serve somewhat different purposes. While information modeling offers the advantage of containing spatially localized data and facilitating correlations, the level of detail provided by two-dimensional drawings can only be achieved in BIM with extended processing times.

Tab. 5: "Structural Condition" property group.

Property	Options
Regulation	UNI 11130:2004
Insect attack - severity	0-5
Insect attack -state	Active, past
Insect attack - spread	Localized, diffuse, limited to the heads
Type of insect	-
Rotting - severity	0-5
Rotting - spread	Localized, diffuse, limited to the heads
Deformation – inflection [cm]	-
Deformation – lateral deflection [cm]	-
Structural cracks – severity	0-5
Loss of efficacy of the connections	0-5
Reductions in section [cm]	-
Link- detailed survey	link
Overall state of conservation	0-5

3.7 Diagnostic Investigations

The results of the diagnostic investigations are also included as properties of the elements on which they were performed. However, a limitation remains: the exact location of the test is not immediately displayed but is provided as textual information. An alternative would be to place symbolic objects, as in (Garcia-Gago, Sánchez-Aparicio, Soilán, & González-Aguilera, 2022), at the positions where the tests were carried out. This approach, however, would complicate the correlation with the structural element and introduces the semantic challenge of classifying an object that does not correspond to a building element.

In the proposed approach, reports and graphs are attached as links. In addition, summary data have been incorporated. Regarding wood investigations (Riggio, Anthony, Augelli, Kasal, Lechner, Muller & Tannert, 2014), tests results can be quantitative, as in the case of hygrometric tests which provides relative humidity percentage, or qualitative, as with Resistograph investigations, which include notes describing wood density profiles or resistance to penetration (Tab. 6).

Tab. 6: "Diagnostic investigations" property group. Properties of this group can be filled in multiple times, one time for each test performed.

Property	Options
Author	-
Date of inspection	-
Instrumentation used	-
Report	link
Photos	link
Results	Qualitative or quantitative depending on the type of test
Test location	near the head, intermediate
Direction	Lateral, top to bottom, bottom to top
Comments	-

3.8 Overall Assessment

Finally, the last group, serving as a bridge between the knowledge phase and the project, is the "Overall Assessment".

This group provides a synthesis of the various evaluations conducted on the structural element and consists of two distinct parameters (Tab. 7). Both parameters express a qualitative rating, choosing among sufficient, slightly insufficient, or strongly insufficient. The first parameter concerns the "Decay" and is linked to the synthetic index of the "Structural Condition" group[9]. The second parameter summarizes the dimensional adequacy or inadequacy of the structural element's section. This information is derived from the synthetic results of the structural analysis, recorded in the "Structural Properties" group.

The ratings for both parameters are then displayed in the 3D model by automatically color-coding each wooden structural element[10]: green

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[9] Ideally, rate 1-2 corresponds to sufficient, rate 3 to slightly insufficient, rate 4-5 to strongly insufficient.

[10] This approach effectively "translates" a methodology commonly used in strengthening projects into the logic of

for sufficient, yellow for slightly insufficient and red for strongly insufficient[11]. The type of intervention is suggested based on these ratings: no intervention, strengthening or replacement.

We have to stress that methodologically (not from an IT perspective), the translation from analysis to intervention cannot be fully automatable. In fact, one of the fundamental principles of restoration interventions is the case-by-case approach. In this regard, one of the major challenges in the digitization of activities related to cultural heritage conservation lies in the methodological control of the partial automation potentially enabled by digital tools. Despite this, when the issue is purely a dimensional deficiency – meaning the section is insufficient but there is no significant degradation – the software will recommend strengthening the element. Conversely, if the element's state of conservation is very poor, replacement is suggested, as it is often necessary even in the case where the beam has an adequate section but is heavily degraded.

When the final goal is to support a planned conservation process, as discussed in (Celli & Ottoni, 2023), a more effective strategy would involve defining a synthetic assessment procedure aimed at developing a "Priority Index" for interventions, thus facilitating the planning of interventions over time (Della Torre, 2021).

Tab. 7: "Overall Assessment" property group.

Property	Options
Decay	sufficient (green), slightly insufficient (yellow), strongly insufficient (red)
Beam dimensions	sufficient (green), slightly insufficient (yellow), strongly insufficient (red)
Suggested intervention	no intervention, strengthening, replacement

4. *Application to a Case Study*

4.1 Brief description of the Case Study

Palazzo Pallavicino (Fig. 5) located in the historic center of Parma (Italy), proved to be a highly interesting case study for testing the development of an information model using the proposed approach. This was particularly due to the extensive data collected during previous research experiences.

Fig. 5: Aerial view of the building with identification of the portion for which the H-BIM model was developed.

The current configuration of the building consists of two blocks with interconnected inner courtyards and is the result of a series of successive transformations. Starting with an initial nucleus dating back to the 15th century, the complex evolved into the form of a *palatium* by the end of the 16th century. However, in the 18th century, the building underwent significant alterations, including the opening of the portico connecting the two courtyards. More notably, the main façade facing Piazzale Santafiora was "straightened", demolished and rebuilt with the southern corner of the building being advanced (Zanazzi & Ottoni, 2023).

For the development of the H-BIM, the focus was placed on the wooden trusses that form the roof of the main body of the building (Fig. 6).

The portion of the building investigated in this study is the result of the 18th-century transformations, which included the façade, vaults at various levels and, consequently, the roof. Therefore, it is likely that the oldest wooden elements of the roof, such as the trusses, date back to these interventions. The roof consists of four "Palladian" type trusses (Fig. 7), featuring a king post and diagonal braces. Some of these trusses include props that reduce the clear span to limit the bending of the rafters. In addition, several solutions for bearing on the wall can be observed.

BIM. Traditionally, plans where structural elements are color-coded can summarize the diagnosis from both a conservation and structural perspective.

[11] Specifically, in the Archicad software, this was made possible by setting "graphic overrides", which automatically determine the color of the object according to the selected conditions.

Fig. 6: Photo of the portion of roof of which the H-BIM model was developed.

This part of the roof has undergone several restoration works, including the replacement of most purlins and joists, as well as the partial modification of the upper stratigraphy. This latter was likely originally composed of wooden battens, with terracotta tiles placed only over the trusses to ensure better waterproofing. Below the examined portion, the large extrados pavilion vault stands out, covering the main hall of the building. This interesting vaulted structure shows typical construction features: ribs along the diagonals, longitudinal and transverse bands with increased thickness, *frenelli* (small stiffening walls), and steel tie-rods dating back to the construction phase.

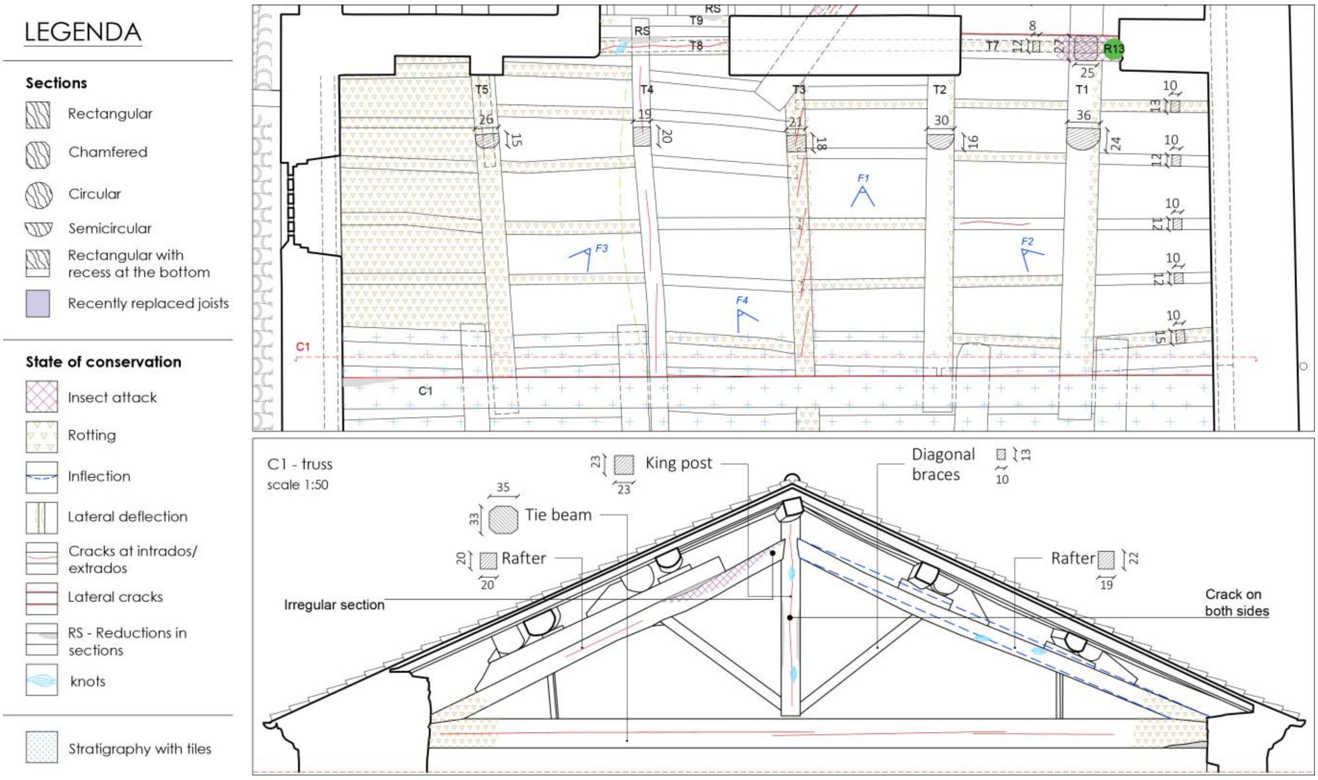


Fig. 7: Two-dimensional drawings with the survey of defects and decay of wood.

The wooden roof had previously been thoroughly surveyed using laser scanning. Additionally, it was the focus of a campaign of investigations in preparation for the drafting of the conservation and seismic improvement project. Although the overall building was in a generally good state of preservation, some critical issues related to the wooden structures were identified.

During prior research, the dimensions of each wooden structural element were surveyed in detail and visual investigations were conducted to classify the beams according to their strength (UNI 11119:2004).

Therefore, all defects (chamfers, knots, shrinkage cracks, etc.) have been punctually mapped. Additionally, for each beam, the presence of decay, rotting or insect damage was assessed, along with any deflections or lateral deformations, necessary to define the structural capacity of the element. Finally, limited hygrometric and Resistograph tests were carried out, together with some sampling aimed at identifying the essence, which was found to be oak.

All information regarding dimensions, defects and decay has been firstly recorded on 2D drawings: plans and detailed sections of each truss, accompanied by textual descriptions, numerous photos, as well as the reports of the tests (Fig. 7).

4.2 Model development and data enrichment

In developing the information system, the primary challenge was to ensure that no data was lost during the translation from the real world conditions (which were already precisely represented in two-dimensional drawings) to the model. Additionally, it was crucial to strike a balance between accuracy, manageability, and the execution time of the model.

Therefore, before providing a detailed description of the non-geometric data, it is important to address the issue of geometric accuracy and simplification. Structural elements are modeled using parametric objects (Fig. 8). Chamfers, for example, can be handled by modifying specially added parameters, while maintaining a constant cross-section that reflects the average value detected by instrumental survey. This means that local reductions in section are not modeled. However, the information regarding geometric irregularities is not lost, as it is included among the object properties.

This approach follows the general principle that certain details, including those related to connections, can be simplified in the modeling but still included as information, prioritizing model manageability. Storing this data as textual information also facilitates querying and

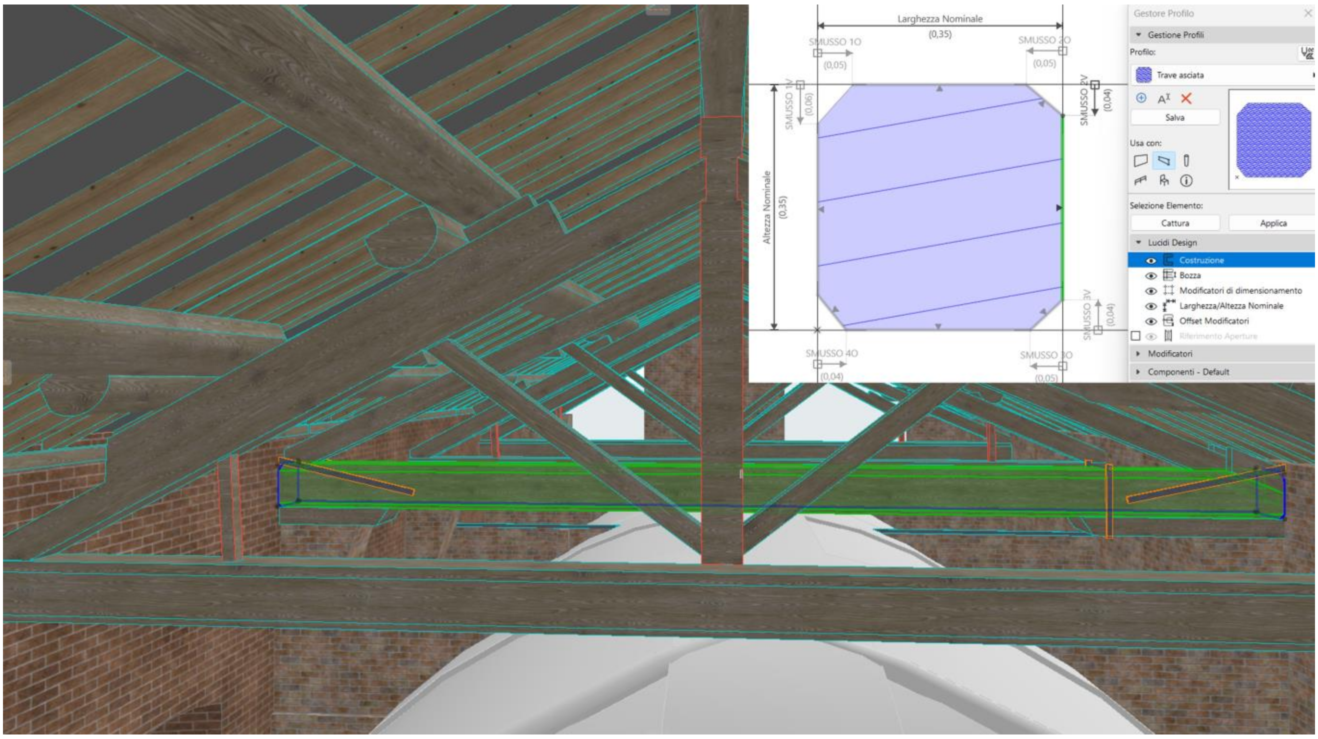
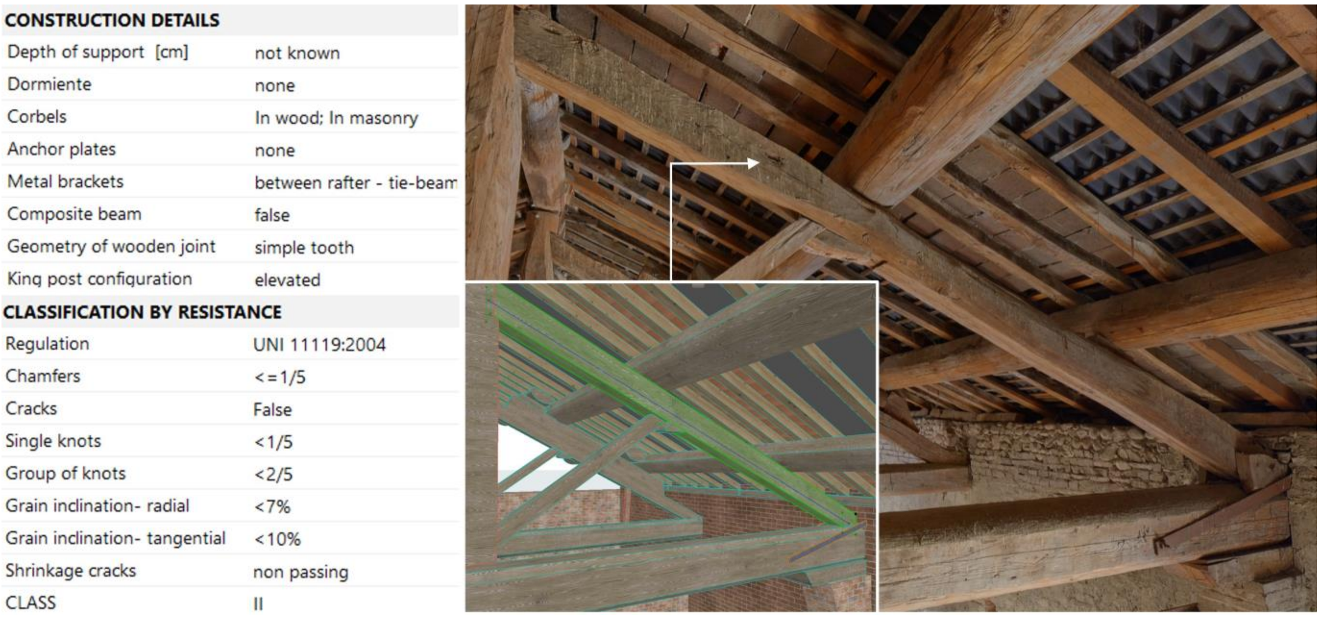


Fig. 8: H-BIM of trusses, parametric profile for modeling of chamfered beams.



CONSTRUCTION DETAILS	
Depth of support [cm]	not known
Dormiente	none
Corbels	In wood; In masonry
Anchor plates	none
Metal brackets	between rafter - tie-beam
Composite beam	false
Geometry of wooden joint	simple tooth
King post configuration	elevated
CLASSIFICATION BY RESISTANCE	
Regulation	UNI 11119:2004
Chamfers	<=1/5
Cracks	False
Single knots	<1/5
Group of knots	<2/5
Grain inclination- radial	<7%
Grain inclination- tangential	<10%
Shrinkage cracks	non passing
CLASS	II

Fig.9: Example of filling in the properties related to “Construction Details” and “Classification by Resistance” for a rafter.

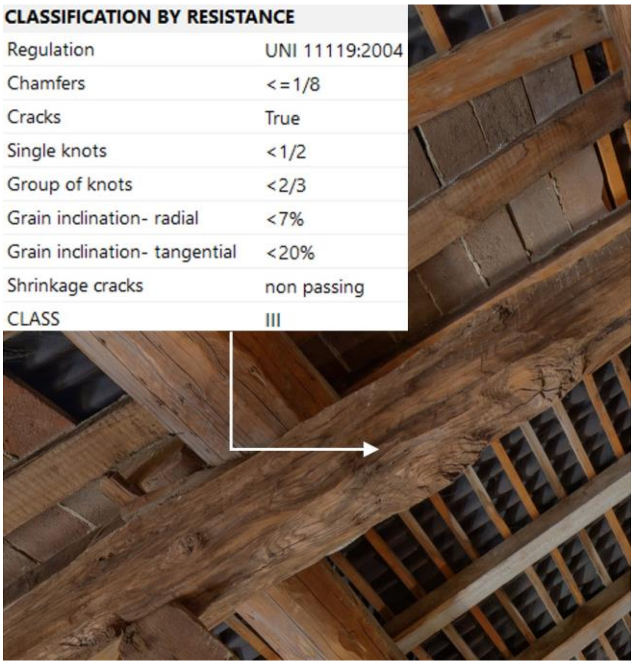
correlation between different datasets, as further explained.

The proposed data structure (Fig. 1) was then populated with data referring to some of the most significant components, aiming to validate the approach presentedin this study.

The most relevant aspects of the application to case study are discussed below. Firstly, the guided survey of construction details, obtained by filling in the proposed properties, enabled the mapping of the different types of connections between rafters and tie-beam of the trusses: some feature wooden corbels, others have masonry corbels and some use metal brackets to connect the corbels to the tie-beam or the tie-beam to the rafter (Fig. 9). Additionally, some trusses have the king post resting on the tie-beam, while in others it is raised.

The “Classification by Resistance” has been applied to some of the rafters. The property describing the chamfers of the section is calculated based on the geometric parameters of the 3D object. The other properties are manually filled in by selecting from predefined options. The category is then automatically computed[12]. Most of the rafters are classified in category II, according to UNI 11119:2004. However, some have strongly chamfered sections or knots of considerable size compared to that of the element, which result in their assignment of class III (Fig. 10).

Analysis of the samples taken revealed that the trusses are made of oak wood. For oak wood, and according to the “Classification by Resistance”, the “Strength class” is chosen between D30 and D40 (classes with “D” are for all broadleaf species), with reference to EN 338:2016 classes. All strength and stiffness properties of the material are assigned accordingly.



CLASSIFICATION BY RESISTANCE	
Regulation	UNI 11119:2004
Chamfers	<=1/8
Cracks	True
Single knots	<1/2
Group of knots	<2/3
Grain inclination- radial	<7%
Grain inclination- tangential	<20%
Shrinkage cracks	non passing
CLASS	III

Fig. 10: Example of “Classification by Resistance” for a rafter affected by major defects.

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[12] This is made feasible through connection with an excel file. In fact, in Archicad “abacuses” containing the properties of modeled objects can easily dialogue with an excel file in which computation are handled.

STRUCTURAL CONDITION	
Regulation	UNI 11130:2004
Insect attack - severity	2
Insect attack - state	past
Insect attack - diffusion	diffuse
Type of insect	woodworm
Rotting - severity	5
Rotting - diffusion	diffuse
Deformation – inflection [cm]	0,0000
Deformation – lateral deflection [...	0,0000
Structural cracks – severity	3
Loss of efficacy of the connections	2
Riductions in section [cm]	4,0000
Link- detailed survey	https://drive.goo
Overall state of conservation	4

Fig.11: Example of “Structural Condition” for a ridge beam affected by severe rotting.

Regarding decay mapping, the proposed properties resulted to be effective in describing the encountered phenomena. In truss rafters and tie-beam, rotting is generally limited to the heads. Some rafters show signs of inflection, and wood props are used to prevent further deformation. A particularly significant property is related to the “loss of efficacy of connections”, as this is one of the most common issues and is widespread both at the wall support and at the connection between multiple wooden elements. More severe decay is observed in some purlins and ridge beams, which are heavily affected by rotting due to water infiltration through the roof (Fig. 11).

The severity score was assigned based on a comparative assessment of the conditions of different elements. In general, a score of 1 or 2 means that the degradation does not significantly affect the structural behavior of the element, while a score of 4 or 5 indicates that the beam has lost most of its load-bearing capacity.

As previously mentioned, an overall rating for decay is assigned. However, this is always a mere guidance and, more importantly, the strengthening intervention to be carried out depends on the specific problem. For example, the criticality may be limited to the connections or beam heads. In such cases, the intervention can be carried out locally (Fig. 12).

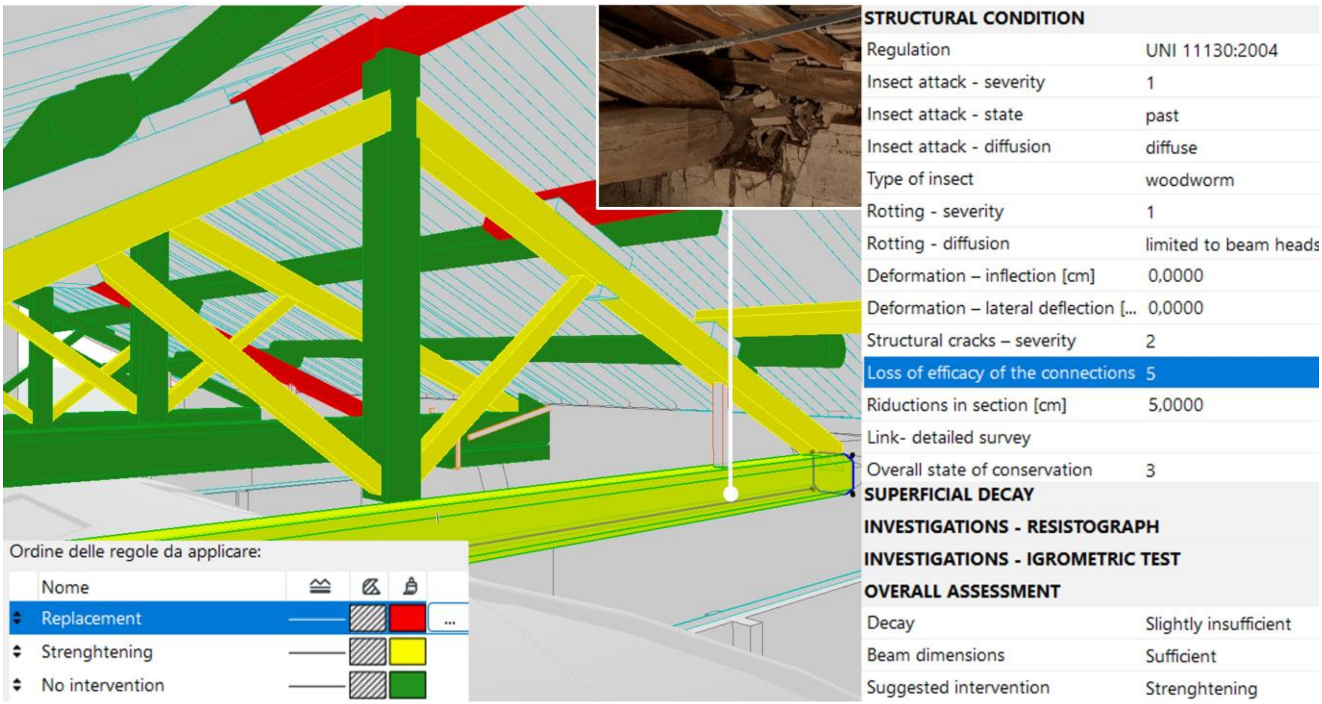
As previously described, the synthetic evaluation about decay is transposed into the “Overall Assessment” group and displayed in the model through the automatic coloring of the beams according to their assessment. Simultaneously, the structural analysis performed on the wooden elements revealed some dimensional weaknesses. Although a detailed discussione of the structural analysis is beyond the scope of this article, the results were incorporated into the “Overall Assessment”, again through qualitative judgments. The combined evaluation of conservation and structural criticalities then leads to the suggested intervention: strengthening, replacement or no intervention.

For example, for the ridge beams that, while having a sufficient average section, are severely degraded (with widespread rotting and reductions in section caused by insect attacks), replacement is suggested. Conversely, the rafters of the trusses, whose state of preservation is acceptable, require strengthening due to their insufficient section.

The underlying idea is that the model can thus guide intervention decisions based on both conservation and structural needs. However, it is important to note that the choice of intervention, and especially the type of reinforcement, cannot be solely based on automatic evaluations or predetermined categories.

5. *Conclusions*

This study outlines a methodological framework for employing H-BIM as a structured and interdisciplinary tool for the knowledge and conservation of wooden structural elements in historic buildings. By introducing customized properties and semantically organizing them into thematic domains, the proposed information system promotes a consistent and guided approach to data acquisition, supporting both analysis and assessment processes.



Ordine delle regole da applicare:

	Nome				
⬍	Replacement	—	▨	🟥	...
⬍	Strenghtening	—	▨	🟨	
⬍	No intervention	—	▨	🟩	

STRUCTURAL CONDITION	
Regulation	UNI 11130:2004
Insect attack - severity	1
Insect attack - state	past
Insect attack - diffusion	diffuse
Type of insect	woodworm
Rotting - severity	1
Rotting - diffusion	limited to beam heads
Deformation – inflection [cm]	0,0000
Deformation – lateral deflection [...	0,0000
Structural cracks – severity	2
Loss of efficacy of the connections	5
Riductions in section [cm]	5,0000
Link- detailed survey	
Overall state of conservation	3
SUPERFICIAL DECAY	
INVESTIGATIONS - RESISTOGRAPH	
INVESTIGATIONS - IGROMETRIC TEST	
OVERALL ASSESSMENT	
Decay	Slightly insufficient
Beam dimensions	Sufficient
Suggested intervention	Strenghtening

Fig.12: “Overall Assessment” of wooden structures. Automatic color assignment according to synthetic assessment.

The proposed methodology aims to bridge the disciplinary gap between conservation and structural aspects. Through the use of predefined data domains (such as that for visual classification of decay and defects), and correlations based on established standards including UNI 11119:2004 or UNI 11130:2004, the model enables a comprehensive understanding of timber structures, integrating morphological characteristics, construction details, state of conservation, and structural performance. Rather than merely serving as a passive data repository, the model acts as an interpretive tool that facilitates the understanding of the impact of historical construction aspects on structural behaviour.

One of the key contributions of this work lies in the proposal of a synthetic evaluation system that condenses the multifaceted diagnostic process into two qualitative indices: one for degradation and one for dimensional adequacy. These are visually expressed within the H-BIM environment, allowing for an immediate understanding of structural criticalities and guiding the selection of intervention strategies, whether strengthening, replacement, or no-intervention.

A key question concerns the extent to which the diagnostic process and the choice of intervention can be appropriately automated. In the illustrated workflow, in fact, some correlations between defects, degradation and structural properties are proposed. These are methodologically grounded, as they partially incorporate regulatory standards. However, other correlations and the last part of the process, namely the translation from analysis to intervention, can only be partially guided by digital tools but intentionally retains a human-centered critical control, in line with conservation principles. In fact, the choice of intervention needs necessarily to be evaluated on a case-by-case basis, and automating the decision is inherently risky.

The case study demonstrates the practical viability and adaptability of this system, showing how traditional 2D documentation and advanced survey data can be harmoniously integrated into an interoperable, semantically rich 3D model.

Looking ahead, the challenge of interoperability remains central, particularly regarding the integration of the H-BIM environment with structural analysis software and monitoring systems. Current limitations of the IFC standard hinder seamless data exchange, especially for heritage-specific attributes. This implies that, despite the correct export of the geometry, there is still a risk of losing the information associated with it.

However, besides the technical and semantic challenges, it is important to focus on the methodological control and interpretation of the data. This means deciding which aspects need to be examined and how to incorporate them into the model without compromising its alignment with reality, while also encouraging collaboration across different disciplines.

Further developments may involve the evaluation of alternative geometric modeling approaches. For example, the implementation of BREP (Boundary Representation) geometries enables the accurate capture of the configuration and geometric irregularities of structural elements with the utmost precision. However, this can be excessively costly in terms of time consumption and model manageability. For this reason, a simplified geometric modeling approach compensated by a rich and detailed information framework was preferred in this study. Nevertheless, the potential advantages of adopting a more accurate geometric representation may still be considered where appropriate (for example in cases where detailed structural analyses are adopted).

Moreover, this study focused exclusively on timber structural elements, with particular attention to the primary load-bearing structure. The other components of the roof construction system – starting with the outer roof finish – have not yet been adequately considered. An accurate information modeling of the roof's enclosure system and its connection to the secondary timber structure would allow for a better understanding of potential causes of wood deterioration, such as those related to water infiltration.

Ultimately, this study indicates that H-BIM, conceptualized as a knowledge-driven framework, possesses substantial capacity to enhance deeply integrated conservation processes. This is particularly relevant for wooden heritage structures, whose complexity demands a comprehensive understanding that includes evaluating the structural impact of construction details, degradation, and defects.

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