Information Modelling for Planned Preservation. The HBIM model of Villa Forni Cerato

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Abstract

The planned conservation of cultural heritage has found a useful tool in the HBIM approach, as the digitization of the process allows for effective access to documents, operations, and projects by various actors in the sector. The adoption of the HBIM approach has seen several key issues emerge, linked to the difficulties of geometric modeling (using a parametric paradigm) of built heritage and the management of big data such as point clouds. With these issues now established, it is time to consider the necessary insights related to information modeling, including for planned conservation. This need has an impact on the practical approach to the work, but also on contractual aspects. In terms of operational practice, information modeling allows HBIM models to be constructed that are easily accessible in all their information, updatable, and easy to use. From a more formal point of view, the definition of the information content in the EIR and BEP is a prerequisite for the proper management of the work and for defining, through an agreement, the characteristics of the work, the results to be achieved, and the methods to be used.

Information modeling is therefore at the heart of this research, which finds its application in Villa Forni Cerato, attributed to Andrea Palladio. The theme developed is that of wooden floors because, on the one hand, they have specific information content and, on the other, because the villa was designed by Andrea Palladio for his timber supplier.

1. Introduction

Preventive and planned conservation of cultural heritage is now not only an established and widely shared concept but has also become an integral part of conservation project design and site management.

The Historic Building Information Modelling (HBIM) sector has made significant progress; however, discussions have largely focused on geometric aspects rather than informational content. The feasibility—and the inherent complexity—of geometric modeling for cultural heritage within the BIM (Building Information modelling) environment, starting from point cloud data, is now well recognized. In particular, it has been observed that the geometric modeling approach in HBIM must be contextualized and tailored for each specific case. However, these studies must advance in parallel with information modeling, as the latter can compensate for and integrate potential gaps in representing highly complex elements. Moreover, information modeling enables the HBIM approach to be oriented toward specific objectives, such as planned conservation, facility management, and beyond.

The information modelling also plays a relevant role because it is closely linked to the definition, including contractual, of the information content of the BIM model. According to the international standard ISO 19650, EIP (Execution Information Requirement) -first- and BEP (BIM execution plan) are probably the most important documents of the process, since they declare the requirements of the client - appointing party- (EIP) and the information offered by the appointed party (BEP). These documents are important not only for the formal management of contracts but also because they allow the BIM objectives and the geometric and informational modeling characteristics to be defined right from the beginning, establishing a balance between the various contents (Ashworth et al., 2023). In the context of HBIM, this information (what to model as geometry and what as information) is strategic given the complexity of some elements. The case of a bent beam is illustrative. In fact, one could consider modeling the beam in its entirety, including its deformation. This is now possible, especially when using parametric tools. However, this could make the HBIM model very heavy and therefore reduce its operability. In this sense, it is possible to decide which information to model through geometry (general dimensions) and which to delegate (e.g., the deflection arrow) to the use of various types of parameters such as text, numbers, links, and images. Of course, this approach to information modelling must be agreed upon by all parties from the outset, in order to build a coherent model.

This research aims to explore key aspects of information modeling within an HBIM framework designed for planned conservation. The revival of Villa Forni Cerato, after a period of neglect, has been made possible by the Fondazione Villa Forni Cerato, which aims to implement an exemplary conservation strategy for the Villa - both in the initial restoration interventions and in the essential phase of planned conservation. The course on "Historic Building Information Modelling" held at the Mantova Campus of Politecnico di Milano within the Master's program in "Architecture Design and History", provided an opportunity for faculty, tutors, and final-year students to deepen their understanding of HBIM for heritage conservation. In this context, the students were asked to think about the geometric modeling of the entire building and to explore information modeling in greater depth for an element. For the latter, they chose to develop a possible theme (historical sources, historical materials, decay, cracking, etc.) and to define the information to be included in the model (parameters) according to the LOIN (level of information needed) scheme. The latter, introduced by ISO 19650, describes the information requirements that the object must contain to address the needs of the professional at that precise moment in the design process. Again, according to the regulation, the information can be of three types: geometric, alphanumeric, and documentary. From this experience, shared with the whole class of students, a particular example has been developed of wooden beams.

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After a short introduction of the state of art, Section 2, the paper describes the architecture and its distinctive features—not only in terms of historical and construction aspects but also in its current phase of revival—in Section 3. The methods used for surveying and geometric modeling are briefly presented in 4.1 and 4.2. Most importantly, Section 4.3 highlights the informational requirements related to the wooden floor structures. The results are summarized in Section 5 and discussed in Section 6 to assess the effectiveness of information modeling.

2. The information modelling for conservation in HBIM: state of art

The importance of BIM applied to Cultural Heritage (HBIM) has grown exponentially in recent years and numerous studies and research papers on this topic have been published. Research journals, ranging from those related to heritage conservation to those dedicated to 3D data acquisition and management, have published numerous reviews on the subject of HBIM to monitor research areas, recent developments, and applications.
An analysis of existing scientific literature reveals several very active research areas.
In general, the effectiveness of BIM applied to existing heritage is recognized, especially for planned conservation. The possibility of managing complex cases through the digitization of objects (architecture) and processes (degradation, mapping, interventions) is confirmed by numerous experiments. Scala Stefano della Torre emphasizes the need to focus on the definition of information content as a fundamental tool for setting up the work correctly (Della Torre, 2021).
Similarly, still in the field of conservation, there is a need to explore ontologies in greater depth, as they are an indispensable tool for enabling interoperability and the management of complex operations in the preservation sector (Moyano et al., 2023). They focus on the semantic enrichment of information, and the interoperability among different representative models within a Common Data Environment, but also put in evidence the lack of connection between the geometric model that contains the semantics and the ontology model.
Other topics are still related to HBIM and planned preservation but are more closely linked to the topic of data processing and geometric modelling. Three-dimensional surveying, classification (Croce et al., 2023), and semantic segmentation of point clouds (Pierdicca et al., 2022), for example, are very topical issues. They are dealing with big data as point clouds, their use and, more generally, with the Scan-to-BIM process (Aricò et al., 2024).
Information modeling for conservation projects, on the other hand, has been dealt with in depth in numerous studies according to the type of data. A common experience is the necessity to manage historical data into HBIM (Bruno, Roncella, 2019). Usually, this need is fixed with the possibility of linking original sources (drawings, projects, historical photographs) to the model or to its part. In this way, the HBIM model of Torre della Pallata plays the role of an archive of data storici e di precedent interventi (Scala et al., 2024).
More technically, the structural field is trying to manage information on the HBIM model in such a way it can be reused also for structural analysis. It is the case of (Saisi et al. 2024) where the authors are trying to define a method to move some information (for example: materials, historical phases and specific masonries) to a FEM model as information content.
Decay and state of conservation is another specific research field of information modelling for planned preservation. It involves two aspects: the choice of modeling methods (in terms of geometry) and the construction of a database and information system. The latter must meet both the needs of the individual building, and the standardized requirements set out in the regulations.
When dealing with the topic of mapping degradation on the HBIM model, there is a convergence of solutions which, at least for geometric aspects, have identified adaptive families as the most flexible tool (Bolognesi et al., 2023).
However, when it comes to the type, quality, and method of managing other types of information, different approaches can be taken. (Zanni et al., 2025) deal with the issue of information modeling of surface degradation through a careful examination of the main regulations and by proposing a well-designed structure for the information content. In their case, there is also an attempt to link the structured information to IFC (Industry Foundation Classes) objects to promote interoperability not only of graphic objects but also of parameters.
Even if not connected with HBIM approach, the richness of information necessary for wood preservation is evident in (Buono, 2023)

3. Villa Forni Cerato

3.1 A project attributed to Andrea Palladio

Villa Forni Cerato (Cappellato, 2021) is located in Montecchio Precalcino, Vicenza, Italy. It is almost unanimously attributed to Andrea Palladio, although its architectural characteristics are simpler than those of other Palladian villas
It gives its name to Girolamo Forni (Villa Forni Cerato Foundation, 2022), a prosperous wood merchant and associate of Palladio who committed its construction. The Villa's construction date is subject to scholarly debate. While some sources suggest it was built around 1565, others propose a later date, post-1568, based on recent research. Forni's involvement in supplying materials for Palladio's projects, such as the Basilica Palladiana and Palazzo Chiericati, likely facilitated their professional relationship. The Villa's dual designation, Forni-Cerato, originates from 1610 when ownership transferred to the Cerato family following Forni's bequest.
It is interesting to observe the drawing/survey of the Villa included by Bertozzi Scamozzi in his "*Le fabbriche e i disegni di Andrea Palladio*" (1776-1783). This document, compared with the current situation, shows how the Villa has come down to the present day with very few transformations, mainly concerning the vertical distribution elements (figure 1).

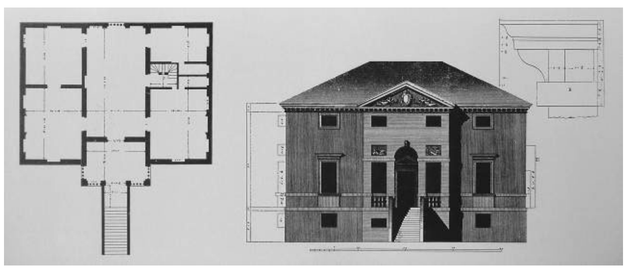

Figure 1. Plan of the first floor and elevation of Villa Forni Cerato in the drawings of Bertozzi Scamozzi.

Villa Forni Cerato was inscribed on the UNESCO World Heritage List in 1996 in recognition of its architectural value and contribution to Palladian heritage. This designation highlights the Villa's importance within the context of Palladio's work and its influence on architectural history.

Villa Forni Cerato is characterized by its compact and harmonious design. The facade is dominated by a central loggia, accessible via a staircase that ascends over the basement level. This loggia features a *serliana*—a tripartite architectural element—with the central arch flanked by rectangular openings spanning the *loggia*'s entire width. This design choice emphasizes the central axis and reflects Palladio's evolving architectural style. The facade's verticality is articulated through the delineation of the cellar, *piano nobile* (main floor), and mezzanine levels, showcasing a clear hierarchical arrangement.

The Villa's interior layout is relatively straightforward, lacking the proportional relationships between room dimensions commonly found in Palladio's other works. This simplicity has led some scholars to question Palladio's authorship, suggesting alternative attributions to figures like Alessandro Vittoria, Vincenzo Scamozzi, or even Forni himself. However, stylistic elements, such as the use of the *serliana* and the overall minimalist aesthetic, support Palladio's involvement.

3.2 Its rebirth in a preservation perspective

After decades of neglect in the 20th century, Villa Forni Cerato has undergone significant conservation efforts. Since 2018, a comprehensive conservation project has involved the Villa. This initiative, driven by patronage and cultural valorization, emphasizes the Villa's historical and architectural significance. In 2023, the establishment of “*La piccola accademia del restauro*"(The Little Academy of Restoration) by the Villa Forni Cerato Foundation marked a pivotal moment in promoting the study and preservation of Palladian architecture.
The aim of the project is to let visitors discover what are the problems and the possible solutions in the restoration of a protected historical property, starting from the historical research on the life of the villa and the absence of any kind of re-functionalization. The Foundation declared very clearly three principles on which the intervention is based (Villa Forni Cerato Website): i. Do not allow any transformation or reuse, ii. Aim for an exemplary restoration, that is, transparent, documented, imitable, because it must be timid, perennial and participatory, iii. Respect the place as “sacred”.
For the preservation intervention, the foundation carried out a large-scale material, decay, and structural analysis campaign, thus providing the knowledge for a thorough and responsible intervention. And, even more important, they shared the results of analysis and restoration in publications (Soragni, 2023).

4. The method

4.1 Survey

The survey of Villa Forni Cerato was carried out using various geomatic techniques, integrated based on a topographic network that served as the framework for the entire project. Laser scanner, photogrammetric techniques (both terrestrial and drone-based), and GNSS (Global Navigation Satellite System) were employed to document the villa and its state of conservation, along with all adjacent buildings.

The survey, described in detail in (Adami et al., 2021), resulted in a point cloud database obtained by integrating laser scanner and photogrammetric data (figure 2). This point cloud served as the primary dataset for the HBIM modeling process, which was conducted within Autodesk BIM environment (Autodesk Recap, Revit). Additionally, orthophotos at a 1:20 scale (figure 3) were processed for both the interior and exterior and used to support the modeling phase.

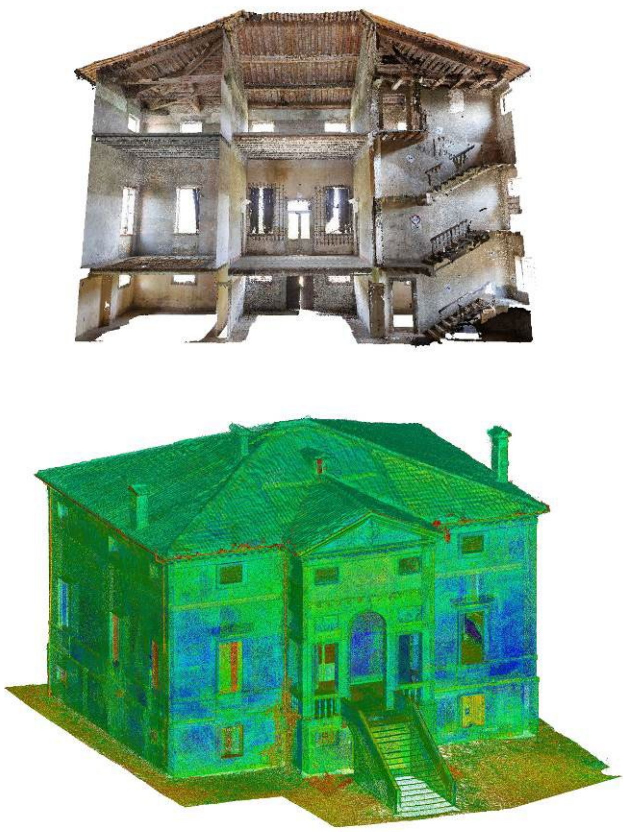

Figure 2: point cloud results of the survey of Villa Forni Cerato: At the top the photogrammetric pointcloud; at the bottom: the laser scanner one.

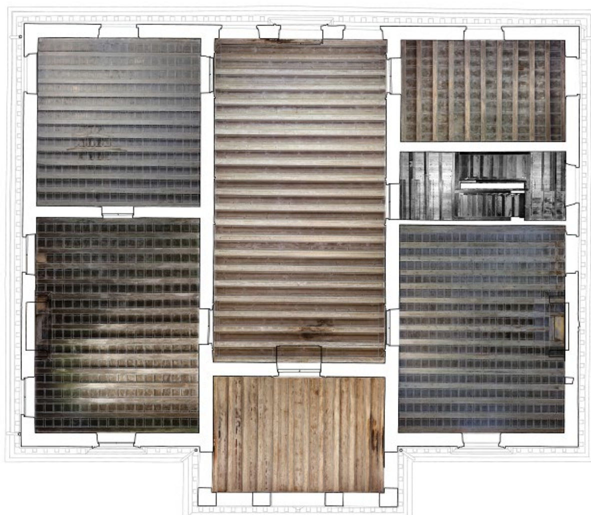

Figure 3: the survey (drawing and orthophoto) of the wooden floor of the *piano nobile* of Villa Forni Cerato.

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4.2 Geometric modelling

For the purposes of HBIM modeling, the entire point cloud was downsampled to a resolution of 5 mm, considered a good compromise between geometric accuracy and usability within the modeling environment. The modeling process followed parametric, object-oriented modeling paradigms, using a classification based on technological elements. Particular attention was given to modeling the wooden floor and roof structures, which were the focus of in-depth information analysis and are closely linked to the historical origins of the Villa—its owner was, as noted, a timber supplier for Andrea Palladio's architectural works.

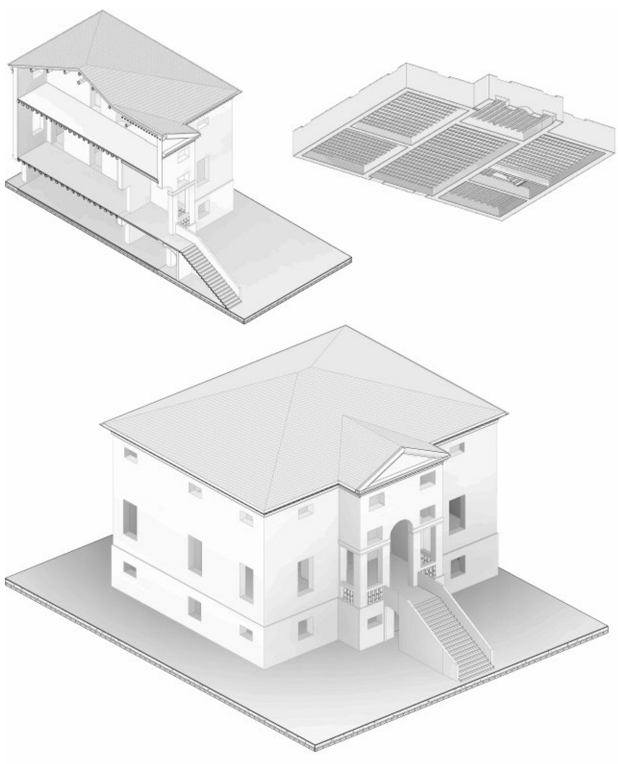

Figure 4 Geometric modelling of the villa. At the top, a vertical section and an opposite view of the first-floor ceiling, at the bottom, the entire model of the villa, from outside.

4.3 Information modelling for planned preservation

Without delving into the regulatory and legal aspects—which differ from country to country—but instead focusing on the asset and its digital *replica* created with the perspective of planned conservation, information modeling can be characterized by two different content levels.
The information modeling covered the entire building in all its main components: walls, floors, roofs, openings, etc. However, it was considered interesting to focus attention primarily on wooden elements. There are several reasons for this choice. From a philological point of view, focusing attention on the wooden parts of Andrea Palladio's timber supplier's house is consistent with the figure of the great architect and his craftsmen. On the other hand, the Villa Forni Cerato Foundation has conducted numerous analyses and diagnostics on the wooden elements, and the results are public. Finally, a third reason is related to the fact that wooden floors are highly three-dimensional and even their minor elements, the beams, cannot be considered flat surfaces. This has led to particular attention being paid to the information modeling phase and, above all, to the mapping of degradation and planned interventions, shifting the focus from surface mapping to 3D mapping as well as the management of related information.
Considering the wooden floor between the first and second floor (*piano nobile*) in Figure 3, the information can be grouped in the following way.
On one hand, there is geometric and identification-related information that uniquely identifies the object while conveying some inherent data. On the other hand, there is a range of information that is strictly linked to the purpose of the BIM model, in this case, planned conservation.
The first group includes dimensions extracted from the model, such as area and volume, as well as the necessary details to identify the subject. For example, consider the need to identify the second wooden beam of the ceiling in the northeast room on the first floor: it is possible to develop an easily constructible code through coding.
The second group, instead, comprises all the information useful for knowledge aimed at conservation. The wood species used for the beam, dendrochronological analyses, penetration resistance measurements, as well as assessments of both widespread and localized degradation, and the overall evaluation of the conservation status, are some of the data required for reaching a comprehensive and accurate evaluation and, consequently, for formulating a design hypothesis. This level also includes all information related to planned conservation, foremost of which is the conservation plan that prescribes all the routine maintenance measures to be implemented in order to prevent the need for significant restoration interventions.
All these pieces of information must be linked to the individual elements of the model and serve as the foundation for subsequent filtering—a very powerful tool. They are integrated into the model as design parameters. Parameters can take various forms depending on the requirements: alphanumeric values, text strings, attached images, or detailed study reports.
As a managing tool, more than the BIM authoring software, there are also "abacus", spreadsheets which summarize all the data in tables to provide a different, sometimes more effective visualization, especially when there are many similar and repeated elements

5. Results

The HBIM model of Villa Forni Cerato was created as a detailed digital representation aimed at facilitating the villa's long-term preventive conservation. The model, informed by precise point cloud data, presents varying levels of detail: most of the building is represented using general typologies (system families) for efficiency and ease of management, whilst the structural timber elements on the second story are rendered with high geometric accuracy. This chosen precision strategy was enacted because to the essential conservation status of the wooden slabs, which have had diagnostic campaigns and focused interventions.
In the model, each timber beam is linked to a collection of parametric variables derived from material analyses and restoration records supplied by the Villa Forni Cerato Foundation (figure 5). The characteristics encompass beam identification codes, family typology, cross-sectional dimensions, seismic anchoring circumstances, conservation status, moisture level categories, and decay risk assessments derived from Resistograph data. Data was obtained from

published structural surveys and diagnostic studies accessible on the Foundation's official website (https://www.villafornicerato.it/en/), namely those associated with the Little Academy of Restoration and the 2023 diagnostic campaign.

A first cognitive approach, fundamental as an element of information modeling, was the definition of the essence of the wood through a xylotomical examination and its dating through a dendrochronological analysis. Investigations on wooden elements began in 2018, as part of a campaign of preliminary diagnostic tests prior to the restoration of the building. This consisted of taking an initial batch of ten samples from the wooden structures of the roof, followed by another 29 samples collected in 2022, when, as the restoration work progressed, it became possible to reach elements that were previously inaccessible, such as the decorated boards of the second floor, thus identifying new elements of interest for the history of the building. The elements analyzed were accurately recorded in the HBIM model in order to provide a precise location of the results, and for each element, the essence and dating of the last ring (where it was possible to reconstruct it) were recorded as an informative parameter.

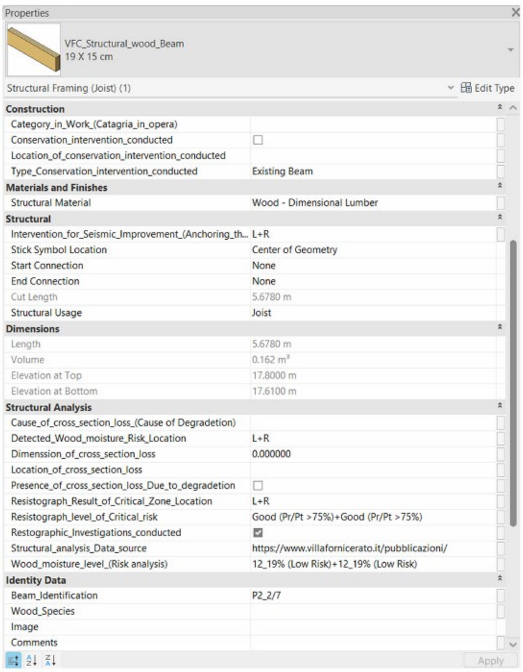

Figure 5 Properties window for each wooden beam. The parameters are of diverse types such as text, link, images, numbers, etc.

Another diagnostic investigation involved the use of a wood penetrometer (or Resistograph) to measure the mechanical resistance encountered by a steel microprobe, with a diameter of approximately 3 mm, when drilling into the wood material (figure 6). The use of this instrument provides a densiometric profile of the sections tested, allowing the extent of any degraded parts to be estimated or any defects in the wood to be ascertained, in order to determine its actual resistant section. In the case of Villa Forni Cerato, penetrometer tests were carried out on a total of 465 samples, ensuring no less than two surveys for each structural element.

The parametric framework was enhanced by employing generic adaptive models. These factors were utilised to spatially delineate critical zones, signifying both the sites of maximum moisture concentration and regions susceptible to structural failure. Colour-coded visual indicators were integrated into these adaptive components, facilitating the distinction of danger categories (e.g., "High Risk" for moisture levels surpassing 20–30% and "Critical" for Pr/Pt Resistograph ratios below 50%). Adaptive models functioned as data carriers, connecting to field observations related to prosthesis placement, anchoring kinds, and conservation categories such as "Existing Beam" or "Wooden Beam Head Prosthesis."

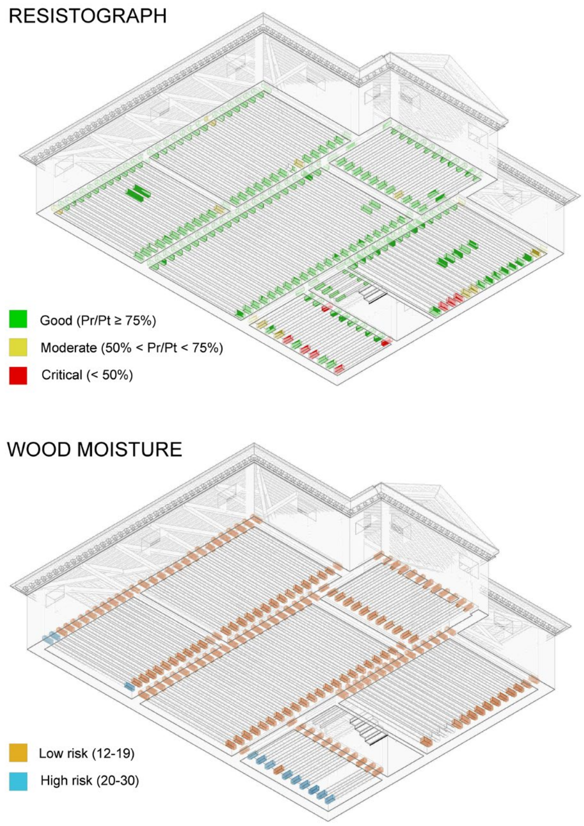

Figure 6: Thematic view of the wooden beams according to the Resistograph Investigation Results (top) and the wood moisture level (bottom). The color of the elements is the result of a filter, based on the values of the specific parameters

This stratified modelling methodology facilitated the simultaneous presence of geometric accuracy and semantic depth. Beam elements were represented both dimensionally and semantically, labelled with essential properties such as:
"Wood essence"
"Restographic_Investigations_Conducted,"
"Conservation_Intervention,"
"Cause_of_Section_Loss,"
thereby augmenting the model's functionality as a dynamic archive. The enhanced data was incorporated through shared and project parameters utilizing scheduling mechanisms inside the BIM environment, assuring uniform integration and facilitating effective information retrieval for analysis or intervention planning.

The resulting HBIM framework constitutes a dynamic and data-rich system, in which each timber element is structured as an informational unit within a query-responsive model (figure 7). The incorporation of criticality indicators via adaptive modelling, along with systematic "parameterization", converts the HBIM model into a knowledge-driven conservation instrument. This method guarantees the traceability of previous interventions and diagnostics while promoting proactive preservation measures consistent with the Villa Forni Cerato Foundation's dedication to exceptional heritage management.

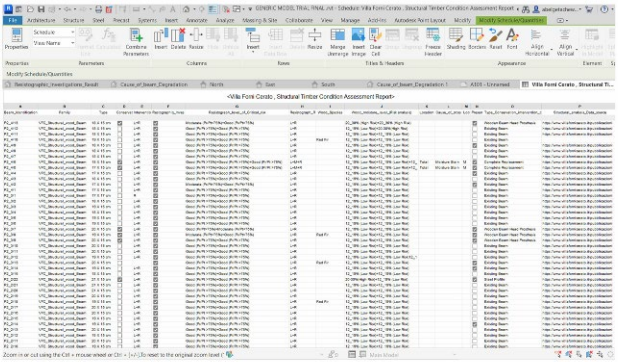

Figure 7: Spreadsheet of all wooden beams, used as a synthesis tool to access all the beams in a single view

6. Discussion

Within the scope of this research, attention is focused primarily on the use of parameters to complete the information apparatus of the objects in the HBIM model.
The examples provided, mainly related to wooden elements, demonstrate the possibility of managing a large amount of information through various types of parameters: text, numbers, PDFs, URLs, images, etc. When exploring the topic of information modeling in greater depth, it becomes clear that these parameters, especially in the context of a conservation project, must be designed and declared from the outset. In fact, the type of parameter will be defined, where to link it, and how to display it appropriately.
In information modeling, it is important to design parameters so that, when possible, they are composed of easily manageable numbers or values (true or false). This is not a simplification but rather a facilitation of management, also because this data is shared with all stakeholders, who may also replace each other over time. This also allows new values or indications to be extracted from the parameters themselves. And these indications must facilitate immediate reading of the model with all its information. The need to 'colour' the elements of the model is not only an aesthetic requirement but also becomes a tool for subsequent evaluations. In this way, the information content can be read in two ways: a first general indication (given, for example, by colour) and a second detailed piece of information (hazard value).
The tests conducted on Villa Forni Cerato have demonstrated another notable aspect of the parameters. As with dendrochronological analysis, updating the parameters is a very easy but effective operation. It simply involves entering or modifying the value of a field. This ease of updating is particularly useful in HBIM models. When dealing with existing architecture, it is not possible to have complete knowledge of every element from the outset. And experience from restoration sites shows that it is precisely after the knowledge phase, when moving on to the construction phase, that new discoveries or observations are made that must be recorded in the model because they contribute to a more complete understanding.

7. Conclusion

The experiment on Villa Forni Cerato, made possible by the scientific approach and data sharing adopted by the Villa Forni Cerato Foundation, highlighted the importance of information modeling in the planned conservation of historical and architectural heritage. Much of the information that emerged during the investigation phase, and then also during the construction phase, played a fundamental role in defining the operational choices of the conservation project, but this was possible because each piece of information was located exactly on the object to which it referred, thus allowing for a localized assessment of any deterioration and all other aspects taken into consideration. The design of the information parameters, based on the results of the various surveys, involved the use of different types of data (text, numbers, URLs, images) depending on the outcome, the thematic views, which aim to synthesize the data so that it is easily understandable and usable.
The decision to pay close attention to information modeling immediately led to certain choices in geometric modeling, thus directing the efforts of BIM specialists in a clear direction from the outset, in accordance with the approaches envisaged, specifically through EIR and BEP.
The interest of the proposed project lies not only in its specific results but also in the method adopted. In fact, the in-depth study of the wooden parts integrates an initial phase of extensive modeling of the building which, thanks to the availability of resources, has gathered specific details that can also be implemented in other sectors as needed. Therefore, the model is not finished once and for all but is constantly evolving and being integrated, as well as ensuring that the data already available is not lost, in line with the circular economy. The use of parametric families, as proposed here after other experiments in other contexts, consolidates the methodological choice in the field of restoration. The degrees of freedom appropriately selected during the modeling phase become the points of value that take on meaning in the context of general simplification.

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