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SCIentific RESearch and Information Technology
Ricerca Scientifica e Tecnologie dell'Informazione
Vol 13, Issue 2 (2023), 125-136
e-ISSN 2239-4303, DOI 10.2423/i22394303v13n2p125

CASPUR-CIBER Publishing, http://www.sciresit.it

HBIM TO SUPPORT THE EXECUTIVE DESIGN OF A RESTORATION. CRITICAL ISSUES RELATED TO GEOMETRIC AND SEMANTIC MODELING

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Abstract

In recent years, the Building Information Modeling (BIM) has been the subject of extensive scientific literature. However, its application in historical construction still requires theoretical research and experimentation. The primary drawback is linked to the fact that historical heritage does not align with the standardization principles inherent in BIM modeling, which is predominantly tailored for new construction endeavors. The application of BIM modeling to the Oratory of S. Giovanni Battista in Bussana Vecchia, Sanremo (Imperia) aims to conduct a critical analysis of the methodology by creating an intelligent parametric 3D model capable of containing all the information necessary for an executive restoration project of the object.

Keywords

HBIM, 3D modeling, geometric modeling, semantic modeling, data enrichment, Architectural Heritage restoration

1. *Introduction*

In the field of architecture and engineering, Building Information Modeling (BIM) is a fundamental reference for new constructions. The National Building Information Modeling Standards (NBIMS) committee of USA defines BIM as a digital representation of physical and functional characteristics of a facility. BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle; defined as existing from earliest conception to demolition. A basic premise of BIM is collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information to support and reflect the roles of that stakeholder (National Institute of Building Sciences, 2017). The standardization of a construction process is a typical characteristic of the whole project. However, the approach introduced by BIM is not yet suitable for historical artifacts.

Historical BIM (HBIM) is considered the application of the BIM methodology to the recovery and management of historical buildings. The first HBIM definition was introduced in 2009 (Murphy, Mcgovern, & Pavia, 2009, Agustin, & Quintilla, 2016). It indicates a new way of modeling existing buildings by generating intelligent three-dimensional objects which can contain and manage information. In recent years, Building Information Modeling (BIM) has been the subject of extensive debate. The scientific community has agreed in identifying HBIM as a true process of creating a model from survey, historical-documentary, metric-morphological, material-constructive, stratigraphic, and degradation data to create libraries of information-dense parametric objects (Dore, Murphy, 2013) (Osello et al., 2016) (Bianchini, Inglese, & Ippolito, 2016) (López et al., 2018).

The modeling of historical buildings is more challenging and laborious compared to new ones due to the geometric complexity of the buildings and the greater amount of data, information, and relationships that the method must contain. The procedure leading to the creation of an HBIM model can be compared to the procedure known as "reverse engineering" (Mammoli, 2019). It's necessary study the existing structure in terms of geometry, elements, materials, and construction processes to replicate them in a digital model.

The application of this tool to historical buildings, which almost never conform to the standardization logic of BIM, there are objective difficulties at various levels, both from a semantic and a computational point of view.

Therefore, the purpose of this work[1], is to investigate on the suitability of the BIM system in historical buildings by conducting a critical analysis of the BIM methodology for creating an intelligent parametric three-dimensional model. It must be capable of containing and managing the intrinsic information of a complex object, functioning as a true "data collector" (Quattrini et al., 2017).

2. *BIM parametric modeling*

The growing interest in information-digital modeling applied to historic architecture has resulted in an increasing scientific literature in recent years. This interest has certainly been driven by the complexity associated with applying the BIM method to historical heritage and the need to simplify tools and procedures.

In the day-to-day use of BIM tools for new construction, the architectural organism is broken down into components, attributing to each of them the relevant semantics. One attributes within an object geometric and material characteristic of the elements, their physical, constructive, and economic properties, thus creating a repository of information. All these data find appropriate fields that are related to each other to generate models consisting of multiple dimensions (4D - time planning, 5D - cost analysis, 6D - asset operational management, 7D - sustainability) (Logothetis, Karachaliou, & Stylianidis., 2015).

The information entered into the BIM database will allow the creation of a virtual parametric model capable of simulating the characteristics and conditions of each element as if they were real. In detail, the project definition level (LOD) must be specified in the BIM in order to determine the degree of accuracy and richness of the information contained in the modeled element.

Over the years, new approaches to the computerized management of Heritage have been tried out with the aim of solving the difficult adaptation of this rigid modeling methodology to a complex and often layered architecture that is difficult to trace back to simple geometric rules, common in BIM.

To date, the translation of geometric information into digital model still does not allow a perfect correspondence between digital model and real object.

Semantically structured parametric models can be used for different purposes by exploiting the potential that is the very essence of BIM methodology. The treatment of HBIM can be declined, due to its interdisciplinary and collaborative vocation character, according to multiple forms and on topical issues such as enhancement and accessibility, historical-archival documentation, and preservation.

Some research proposes software tools for building information modeling allowing semantic modeling of 3D data and further enrichment with non-geometric building information through the inclusion of new concepts on historical documents, images, evidence of decay or deterioration (Garozzo, Lo Turco, & Santagati, 2017; Brumana, Ioannides, & Previtali, 2019).

Other studies have presented protocols to facilitate the organization of information in the pre-model phase, in accordance with the collaborative HBIM methodology. The application of such protocols results in improved management of the documentary material, projects, interventions, and uses of the asset in order to achieve effective management (García-Valldecabres, López González, & Cortes Meseguer, 2020).

The possibility of noting on models' information regarding the state of preservation, phases of transformation and change of the artifact constitutes one of the most relevant focuses about the use of such tools in the management of the historical built environment (Mammoli, 2019). Recent studies show how BIM tools can be used to record the historical development of a building using the fourth dimension (Mammoli, Mariotti, & Quattrini, 2021).

Realizing the geometry of an HBIM model as closely as possible to reality is one of the most relevant and discussed issues. The historical heritage consists of a complex and often layered architecture that is difficult to reduce to simple geometric rules. (Osello et al. ,2016). BIM methodology uses different working methods.

[1] This work is part of a master's thesis in Building Construction and Architectural Engineering "HBIM and Augmented Reality to support the executive design of a restoration. Critical issues and possible application methodologies", developed by Margherita Valentini at the Department of Civil, Chemical and Environmental Engineering (DICCA) of the University of Genoa (Italy), supervisors prof. arch. Carlo Battini and prof. arch. Rita Vecchiattini, co-supervisor arch. Michele Cogorno (Segretariato Regionale del Ministero della Cultura per la Liguria).

Geometry, which can be acquired from range-based or image-based survey systems, involves reconstruction work that sees a close connection between point cloud acquires and parametric geometry (Campi, Di Lugo, & Scandurra, 2017; Giannattasio, Papa, D'Agostino, & D'Auria, 2020). Modeling methodologies such as Cloud to BIM lead to the construction of geometrically reliable models (Brusaporci, Maiezza, & Tata, 2018; Bianchini, Nicastro, 2018).

New tools see semi-automatic conversion of imported point cloud within BIM software through recognition and automatic generation of parametric objects using plug-ins for specific patented in recent years.

These tools are able to recognize objects consisting of simple geometric primitives and those work with recognition and best-fitting algorithms. However, the process is ineffective or excessively slow when attempting to represent complex and irregular historic building geometries (Attenni, 2019). No algorithm that automates the "Scan-to-BIM" workflow has gained wide acceptance in the AEC community.

Despite criticism, this method is being updated and implemented to improve parametric modeling of historic architectural heritage (López et al., 2018) (Table 1).

Tab. 1: Modeling basis - automatic modeling point cloud

Advantages	Disadvantages
Almost entirely automatic modeling (López et al., 2018)	Effective only for modest dimension geometries (Attenni, 2019)
Good computational speed with simple geometries (Logothetis et al., 2018)	The model is not solid but composed of surface meshes.
Good accuracy of the final model with simple geometries (Logothetis et al., 2015)	Only effective if the point cloud has a high level of accuracy (Attenni, 2019).

In the context of historic buildings, to date there is no software capable of fully automating the modeling of buildings characterized by complex morphologies. The methodology that comes closest to this case study is the conversion of mesh to NURBS. This is always a semiautomatic procedure since it requires manual correction by an operator (Quattrini et al., 2017; Garozzo, Lo Turco, & Santagati, 2019) (Table 2).

Tab. 2: Modeling basis – semi automatic modeling point cloud

Advantages	Disadvantages
Semi-automatic modeling that reduces processing time by half compared to manual methodology of 3D elements	The effectiveness of the method is primarily limited to new constructions.
A method capable of recognizing objects composed of geometric primitives.	In many cases, it can only recognize objects composed of simple geometric primitives. (Barazzetti et al., 2015)
Good accuracy of the final model (Barazzetti et al., 2015)	Conversion of elements that fall within local families, which in turn add weight to the project file.

More common practice, which is less precise, is to import two-dimensional vector files into the BIM environment for reconstruction of 3D models. Most architecture, engineering and construction companies have gradually abandoned drawing-based CAD technology in favor of BIM solutions created to provide a complete building view based on three-dimensional models These models are composed of so-called "smart objects" that contain information about themselves and their relationships to other objects within the same model, and can be constructed or modified to allow their propagation and modification (Ippolito, Attenni, & Darwa, 2023). This procedure inevitably implies a very pronounced synthesizing of much geometric information that determines LOD (level of definition), now almost abandoned to make room for LoIN (Level of Information Need) introduced by UNI EN ISO 19650 (Pavan, Mirarchi, Cavallo, & De Gregorio, 2020) (Table 3). This different management of the parametric model aims to avoid too excessive management of information in the elaboration of an intervention project, harmonizing the level of detail required concerning geometric (Level of Geometry, LOG), alphanumeric and documentary (Level of Information, LOI) data.

Tab. 3: Modeling basis – AutoCAD drawings

Advantages	Disadvantages
Vector drawings are easier to use compared to parametric modelling.	Method characterized by extreme simplification

Linked AutoCAD files allow for their subsequent updates.	Imported AutoCAD files do not allow for their subsequent updates.

3. *Semantic modeling*

The hallmark of the software H-BIM is the ability to semantically enrich a model, that is, to assign descriptive attributes to all its component parts.

Making a good model makes it easier to read and understand the building. For a long time, HBIM-based work focused on representing and mapping distinctive geometric features of the architectural complex according to point cloud data. More recently, HBIM models have been studied as containers of a large amount of information related to geometry, materials, structural behavior, construction phases, stratigraphic analysis, microclimatic characteristics, energy execution and restoration works.

However, the irregularity of historical architecture requires further specific reflections regarding its modeling. Some studies have focused on the integration of BIM modeling with an ontology-based knowledge system (Simeone, Cursi, 2016; Acierno, Cursi, Simeone, & Fiorani, 2016), while others have investigated the potentialities related to the parameterization within BIM software of architectural elements and the consequent creation of shared libraries (Chiabrando, Lo Turco, & Santagati, 2017; Quattrini, Battini, & Mammoli, 2018).

The preservation and transmission of knowledge today is entrusted mainly to the world of ontology informatics. It arises from the need to communicate, organize data and information among the various actors in the process. Ontology integrates within the same descriptive system concepts of a knowledge domain and relationships between concepts. All ontologies are connected to create a single description of the artifact. The creation of semantically aware 3D models populated with data that can be investigated through ontologies ensures true interoperability in the field of Cultural Heritage. Despite the numerous studies conducted in this regard, it is evident that even today the parametric libraries available in the BIM environment are not flexible enough to be used. The architectural heritage is extremely varied and does not have a homogeneous amount of design and construction solutions that are homogeneous with each other such that they can be placed in a unified set of rules (Table 4).

Tab. 4: Semantic modeling - Ontology

Advantages	Disadvantages
Use of ontology, which allows the BIM model to be enriched with various information.	Use of extensions related to the world of programming, which is difficult to understand for those who do not work in the IT field.
The processing of specific ontologies by *ontology editors* enables the understanding of heterogeneous information related to a building under study. (Simeone & Cursi, 2016)	The method need for insights into the cataloging of all the information that can be included in the parametric model. (Mammoli, 2019)
The creation of 3D model with the integration of ontologies contributes to improving communication among different professionals.	

4. *The case study*

The paper presents a critical analysis of the BIM methodology for the creation of an intelligent parametric three-dimensional model applied to a specific case study.

The experimentation on a real case study was conducted on the Oratory S. Giovanni Battista of Bussana Vecchia municipal territory of Sanremo (Imperia - Italy). The building is currently the subject of a restoration project by *Segretariato Regionale del Ministero della Cultura per la Liguria*. The oratory is located on the top of a hill in the ancient part of the town, next to the church (fig.1).

The building was constructed in the 17^{th} century with load-bearing stone masonry and consists of a single rectangular nave with an apse, once covered by a lunette-vaulted ceiling, which is now almost entirely collapsed. The earthquake of 1887 caused the collapse of many buildings in Bussana Vecchia, which was rebuilt in the downstream area (Bussana Nuova). The oratory remained in such a state of disrepair that it caused the vault to collapse in the first half of twentieth century. The building was modified in 18^{th} century to include an organ on the counter-façade, resting on large masonry arch. New side doors and windows were opened. The internal decoration was also modified by the insertion of large paintings on the walls and by the painting of the apse and niches (Calvini, 1987; Ivaldi & Marro, 1994) (fig. 2).

Currently, the building is in poor condition with significant structural issues. The exposure to weather events due to the lack of a roof and the absence of protective elements on the wall crests, combined with structural problems, has accelerated the degradation of both the structural and decorative elements.

Fig. 1: Aerial view oratory S. Giovanni Battista – Bussana Vecchia, Sanremo (Imperia-Italy)

Fig. 2: Internal view oratorio S. Giovanni Battista – Bussana Vecchia, Sanremo (Imperia, Italy)

5. The case study

For the accurate representation and understanding of the building's condition, an architectural survey of the structure was conducted using technology Laser Scanner equipment (table 5), high-resolution digital photogrammetry (table 6), aerial photogrammetry (table 7)[2].

Tab. 5: Technical characteristics Laser Scanner Tecnology

	Laser Scanner 3D Trimble X7
Measurement noise	< 3 mm a 60 m with 80% albedo
Precision	2 mm
Scanning speed	Until 500 kHz

Tab.6: Technical characteristics terrestrial topography

	Nikon D610
Sensibility ISO	ISO 100-6400

Tab.7: Technical characteristics terrestrial topography

	DJI Mavic 3T
Camera resolution	48 megapixels
Speed	6 m/s

This process yielded a complete point cloud of the object and AutoCAD drawings related to plans, elevations, sections, and their corresponding orthoimages. Autocad 2023 was used for this procedure.

Furthermore, for an in-depth understanding of the object, mappings of materials and existing degradation were also conducted[3].

The study was carried out exclusively using Autodesk Revit 2023 software, which was the only BIM modeling tool available through an educational license from the University of Genoa.

6. Geometric modeling - critical reflections

The geometric modeling foundation used for the case study was the point cloud, which was supplemented by the provided AutoCAD drawings. The imported point cloud serves as the most effective modeling foundation for the object. Each

[2] The survey was carried out by the Modus Architecturae studio of Genoa (Italy) for Segretariato Regionale del Ministero della Cultura per la Liguria.

[3] These mappings were prepared as part of the material diagnostic analysis of the oratory by the Architecture and Design Department (DAD) - University of Genoa (Italy), prof. arch. Stefano F. Musso and Prof. arch. Rita Vecchiattini.

point contains measurable geometric information, which made possible to query the point cloud and extract all useful information, such as heights, lengths of elements, and depths. To compensate for the low density and precision of the point cloud and the inability to use it for loadable families, in some parts of the object, floor plans, elevations, and sections of the building were imported to support the point cloud. This procedure was found to be less precise in terms of error but more time-consuming compared to the previous method. Elevation drawings were created in an AutoCAD drawing project. They were not automatically recognized as elevations by the Revit software, so manual procedures were required to change the global User Coordinate System (UCS) in AutoCAD (fig.3). This procedure was relatively straightforward but time-consuming (table 8).

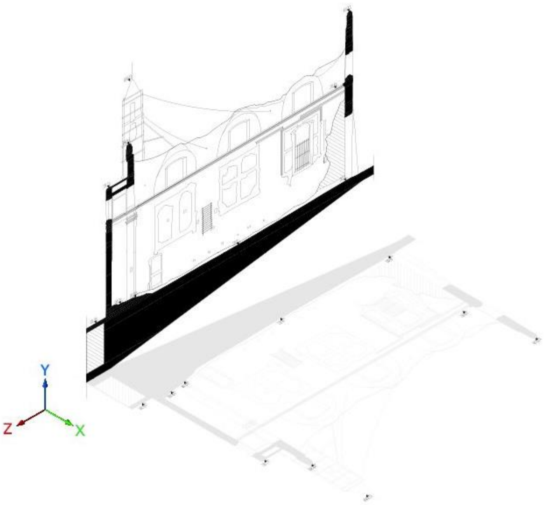

Fig. 3: Import from AutoCAD longitudinal section to Autodesk Revit project.

Tab. 8: Comparison of the two modeling bases

	Point cloud	Autocad drawings
Precision	Good (0.5 cm)	Acceptable (0.8 cm)
Speed	Good (2:30 h)	Poor (7:30 h)
Results	Good	Acceptable

Below, only some of the architectural elements of the oratory will be described in detail. The selection is made to facilitate a better understanding of the challenges encountered during this experimentation phase. Specifically, we will highlight the difficulties encountered and the viable solutions found. Most of the architectural elements inside the oratory have been modeled as local families. The reason for this choice is their greater geometric editability due to the conservation state of the oratory. Elements that are more degraded present significant modeling challenges, and local families offer better editing capabilities. Loadable families provide the same geometric editability but have the disadvantage of not being able to use the point cloud as a modeling basis.

On the other hand, the wall elements were primarily created using system families. The components in this category form the structural framework of the project and do not allow for free "graphic" editing. If one wants to make changes to the family, there is the need to duplicate it and then rename it. The changes that can be made are related to the distinctive characteristic values of the family (thickness, height, length, profile, etc.).

The first challenge encountered with the wall structures of the oratory relates to their stratigraphy. They are composed of a stone core with layers of exterior and interior plaster. There are two types of coatings: multiple layers of plaster applied on top of each other and adjacent coatings on the same plane. Modeling this element occurred after several unsuccessful attempts, such as trying to create an Autodesk Revit "layered wall" element and using the "instance wall layer management" command. The resolution method for this issue required the creation of different "wall" instances to be placed alongside the stone core. The edit profile comand was used in order to follow the irregular geometry of the layers due to the structure's degradation. This resolution method proved to be the most effective but has a conceptual drawback. Creating a wall by creating different wall instances loses the concept of a wall as a single element, decomposed internally into different layers (fig.4).

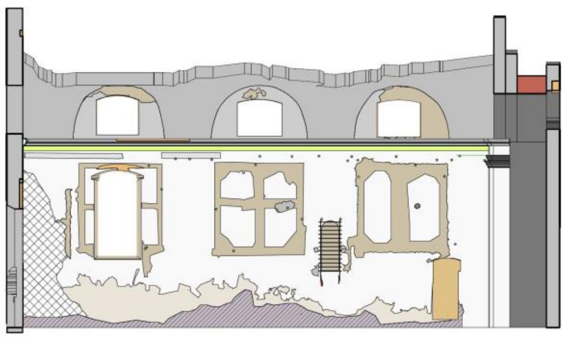

Fig. 4: Longitudinal section internal east wall within the Revit software

Tab. 9: Results of the wall instance's construction

	Wall instance – finishing layers
Geometrical precision	Good (0.6 cm)
Speed	Poor (6:30 h)
Results	Acceptable

Through the "edit profile" command of the wall element, the wall crests were modeled, which have jagged edges in their structure.

All non-plumb and non-linear wall elements were modeled as local families for easier editing.

The geometric modeling of this type of local family involves creating simple shapes related to a reference plane through the generation of the five solid primitives and corresponding voids with five modeling techniques (extrusion, union, extrusion along a path, union along a path and revolution). One of the main challenges encountered is the requirement to work with elements referring to a work plane. Elements following a curvilinear path were not created due to the inability to establish a reference plane. Another challenge was related to the excessive weight of this type of family. At the beginning of the oratory modeling, the possibility of degrading the project file's performance was not considered because the object of study is of a modest size. The excessive use of local families has made the software less manageable, even in modeling simple geometries.

The vaulted roof of the oratory was modeled as a local family and proved to be the most difficult element to create and manage. It is no longer present due to transformations caused by ongoing degradation. The oratory was originally covered by a lunette-vaulted ceiling, which is now almost completely collapsed due to damage from the 1887 earthquake and subsequent neglect. Given the complexity of the element, it was modeled as a nested local family.

Specifically, the modeling process involved creating the original vault by creating a solid geometry using the "extrusion" command based on the profile of the vault. Subsequently, a subtractive void was created, also using extrusion, to match the jagged edges from the point cloud of the remaining part of the vault. Modeling the different layers of the vault's covering presented a challenge for which various resolution techniques were evaluated, all of which were unsuccessful due to its curvilinear nature. Ultimately, it was decided not to geometrically model the stratigraphy of the vaults but only to semantically enrich the object with information related to the various plaster layers present (fig.5).

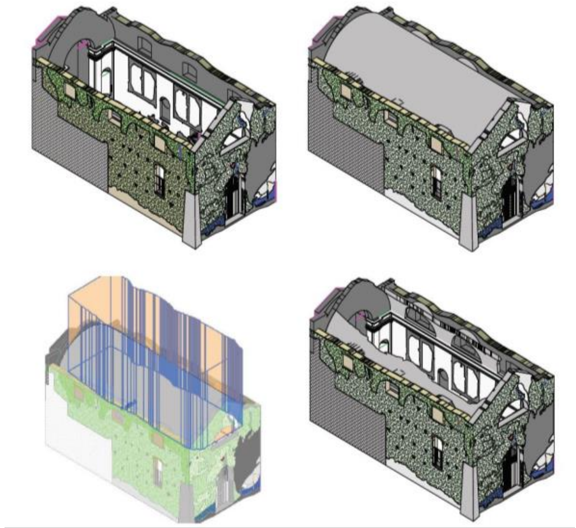

Fig. 5: Costruction's process of vaulted roof of the oratory

Tab. 10: Results of the vaulted roof's construction

	Local model - vault
Geometrical precision	Good (0.6 cm)
Speed	Poor (7:30 h)
Dimension	Great
Results	Acceptable

In all cases where it was not possible to geometrically model a part of the architectural element, the approach taken was to address the issue by enriching the relevant element only semantically.

7. Semantic modeling - critical reflections

From a semantic perspective, standardization of elements has been carried out through the establishment of a specific level of definition. This choice has resulted in a greater correspondence between the virtual model and the real object but at the same time, a significant reduction in software performance. The level of definition used for modeling within the software was LOD F (executed object). Each component within the project contains complete or partial information regarding its geometric characteristics (thickness, area, volume), material and construction characteristics, architectural features, and information concerning the existing degradation and planned processing. significant issues have been encountered in the semantic editing of elements belonging to system families.

To semantically enrich an element of this category, it is possible to use the internal system parameters of the project file, but they follow a strict standardization process. Within this type of family, it is not possible to add additional parameters beyond those already present. For example, for "wall" elements, it was not possible to insert specific information related to degradation and planned processing. Only generic information regarding the type of degradation present and the reference to the planned processing within the “capitolato speciale d’appalto” for the restoration project of the oratory has been included (fig. 6).

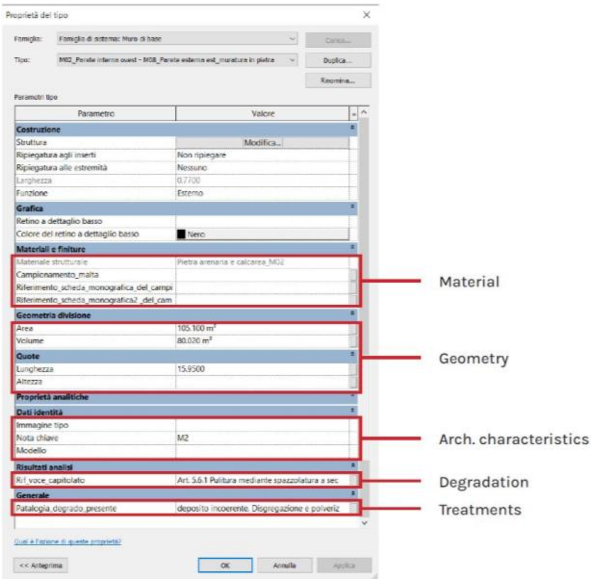

Fig. 6: Parameters of a generic system family

The category of local families presented different challenges. This type of element has limited capacity to convey information within the project and has poor automatic parameterization capabilities. In many cases, it was necessary to override the software and manually transfer information from the local family editor to the project file. Consequently, the process turned out to be slow and laborious (fig.7).

The treatment of degradation and related processes in the BIM environment is directly addressed within this paragraph concerning semantic modeling because the latter has had a greater influence on the modeling choices of components than geometric modelling.

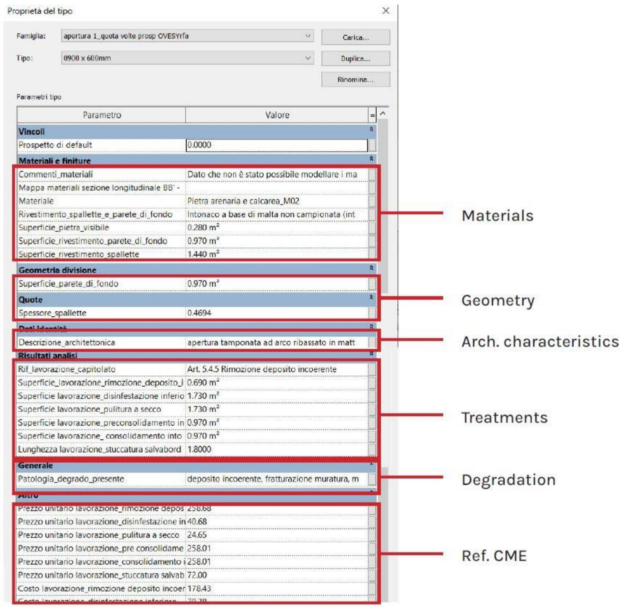

Fig. 7: Parameters of a generic local family

To date, orthophotos are among the most frequently used supports for the representation of degradation and interventions. However, the use of this type of representation involves the production of multiple information files that identify a single section, plan, or elevation, which can lead to knowledge dispersion. Furthermore, areas and lines on non-BIM software maps are not mutually relatable and remain clearly not queryable.

The study of methodology HBIM model has an important role in the study and quantification of degradation. In this study, various modeling methods were experimented with. The model needed to have geometric and semantic information about the type of degradation present and allow for three-dimensional visualization. Among the methods experimented with, the one that proved most effective was related to the creation of a generic local model. This type of family can be viewed in both 2D and 3D views. Furthermore, it was possible to assign a unique texture and pattern to each type of degradation to distinguish it from others. This process yielded the geometries of the degraded areas on flat surfaces.

Concerning the pathologies present within the Bussana Vecchia oratory, this family managed to represent widespread and local pathologies but not the fissure pattern to address this issue, the elements falling into this category have been represented as 'model lines,' visible in 3D but not semantically editable (fig. 8).

From a semantic perspective, the generic local model provided the geometric parameter "volume" and the ability to set the material. From the aforementioned geometric parameter, additional semantic family parameters were manually derived and assigned. Due to the complexity of these elements, the creation of these components resulted in a decrease in software modeling performance (fig. 9).

The processing steps were modeled using the same procedure, with the difference being that the surface restoration interventions were mapped within the "project phase" of the Autodesk Revit project file and not in the "existing state" phase like all the components described earlier. This resulted in a more intuitive visualization of the processes (fig. 10).

Fig. 8: Comparison between the Revit model and the real geometry of degradation pathologies and fissure pattern on the inner east elevation of the oratory.

8. Conclusions

Parametric modeling using BIM shows how information can be stored in an organized form, defining semantically structured modeling for technical purposes, as well as being usable for others. However, this system has some critical issues that make the BIM system still being defined and optimized when applied to historic buildings. Available tools, such as the Revit software employed in this work, seem to present some difficulties in both modeling and data management.

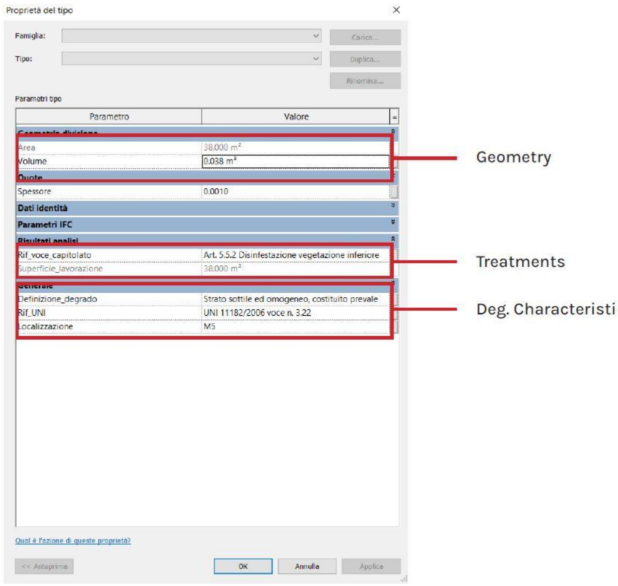

Fig. 9: Parameters of a degradation pathologies - local family

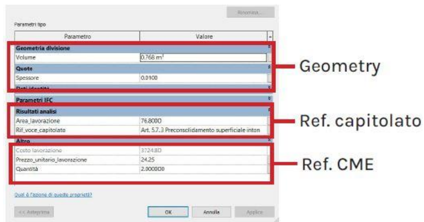

Fig. 10: Parameters of a Restoration project processing – local family

The work described attempts to propose solutions to problems and critical issues in the methodology that have already emerged in other case studies through the analysis of developments in H BIM technology.

The result obtained in the BIM environment is a semantically rich parametric model of the Bussana Vecchia oratory (fig. 11). The data entered within the modeling software allows to give information related to geometry, materials, state of preservation and planned restoration work.

Several critical issues were found in the experimentation, which were only partially solved always within the framework of Autodesk Revit software. The program, unfortunately, is not adapted to the characteristics of a historic building and consequently did not allow to work on all the geometric peculiarities of the oratory. It was possible to realize in BIM about 85 percent of the constituent elements of the object. Most of the architectural elements within the oratory were modeled through local families, which resulted in long average processing times negatively affecting the performance of the software.

It is to be hoped that in the near future, the commission sought by the European Union to define standards for HBIM may define a single standard that will push the various software companies to develop applications that can more easily manage historic architectural assets.

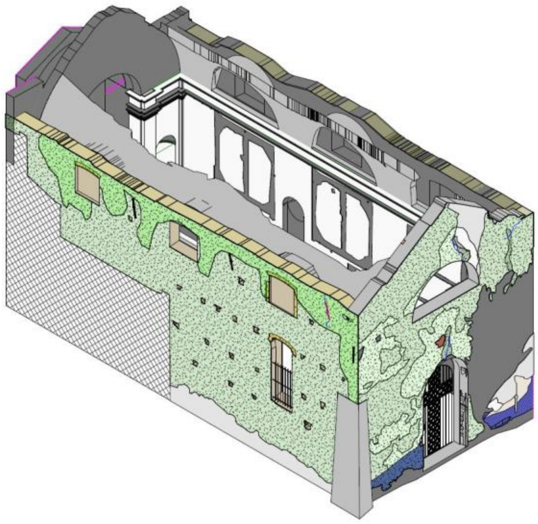

Fig. 11: View of the 3D model within the Autodesk Revit software.

References

Accettulli, E., & Farinati, P. (2021). *Historical Bim: la metodologia applicata agli edifici.* Milano: Tecniche Nuove.

Acierno, M., Cursi, S., Simeone, D., & Fiorani, D. (2016). Architectural heritage knowledge modelling: An ontology-based framework for conservation process. *Journal of Cultural Heritage*, *24*(3-4), 124-133. http://sciencedirect.com

Agustin, L., Quintilla, M. (2019). Virtual reconstruction in bim technology and digital inventories of heritage. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* XLII-2/W15, 25-31. https://doi.org/10.5194/isprs-archives-XLII-2-W15-25-2019.

Attenni, M. (2019). Informative Models for Architectural Heritage. *Heritage, 2*(3). 2067-2089. https://doi.org/10.3390/heritage2030125.

Barazzetti, L., Banfi, F., Brumana, R., & Previtali, M. (2015). Creation of Parametric BIM Objects from Point Clouds Using Nurbs. *The Photogrammetric Record, 30*(152), 339–362. https://doi.org/10.1111/phor.12122

Bianchini, C., Inglese, C., & Ippolito, A. (2016). Il contributo della Rappresentazione nel Building Information Modeling (BIM) per la gestione del costruito. *DISEGNARECON*, *9*(16), 101-109.

Bianchini, C., & Nicastro, S. (2018). The definition of the Level of Reliability: a contribution to the transparency of Heritage-BIM processes. In T. Empler, F. Quici, G.M. Valenti (Eds.). *3D Modeling & BIM. Nuove frontiere* (pp. 228-245). Roma: DEI.

Brumana, R., Ioannides, M., & Previtali, M. (2019). Holistic heritage building information modelling (hhbim): from nodes to hub networking, vocabularies and repositories. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLII-2/W11, 309–316. https://doi.org/10.5194/isprs-archives-xlii-2-w11-309-2019.

Brusaporci, S., Maiezza, P., & Tata, A. (2018). A framework for architectural heritage HBIM semantization and development. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLII*(2), 179-184. https://doi.org/10.5194/isprs-archives-XLII-2-179-2018

Calvini N., (1987), *Bussana dall'antico al nuovo paese*. Sanremo (IM), IM: Famija Sanremasca.

Campi, M., Di Luggo, A., & Scandurra, S. (2017). 3D Modeling for the knowledge of Architectural Heritage and virtual reconstruction of its historical memory. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLII*(2), 133-139. https://doi.org/10.5194/isprs-archives-XLII-2-W3-133-2017

Chiabrando, F., Lo Turco, M., & Santagati, C. (2017). Digital invasions: from point clouds to historical building object modeling (H-BOM) of a UNESCO WHL site. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLII*(2), 171-178. https://doi:10.5194/isprs-archives-XLII-2-W3-171-2017

Dore, C., & Murphy M. (2013), Semi-automatic modelling of building façades with shape grammars using historic building information modelling. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XL-5/W1, 57–64. https://doi.org/10.5194/isprsarchives-xl-5-w1-57-2013

García-Valldecabres, J., López González, C., & Cortes Meseguer, L. (2020). Definition of a Protocol for Information Management and the Creation of the HBIM Model. *Graphical Heritage*, 176–188,. Springer. https://doi.org/10.1007/978-3-030-47979-4_16

Garozzo, R., Lo Turco, M., & Santagati, C. (2019). Information Models to Manage Complexityfor an Integrated Knowledge Project (JD). *Diségno, 4, 225–236*. https://doi.org/10.26375/disegno.4.2019.21

Giannattasio, C., Papa, L.M., D'Agostino, P., & D'Auria S. (2020). The BIM Model for Existing Building Heritage: from the Geometric Data Acquisition to the Information Management. In L. Agustín-Hernández, A. Vallespín Muniesa, A. Fernández-Morales (Eds.). *Graphical Heritage*, 311-322. Cham (CH): Springer. https://doi.org/10.1007/978-3-030-47979-4_28

Ippolito, A., Attenni, M., & Darwa R. (2023). HBIM as a tool for heritage presentation of santa maria in trastevere. *SCIRES-IT - SCIentific RESearch and Information Technology, 13(1).* https://doi.org/10.2423/i22394303v13n1p53

Ivaldi, W., & Marro, R. (1994). *Bussana Vecchia*. Torino, TO: Testo & Immagine.

Logothetis, S., Karachaliou, E., & Stylianidis E. (2015). From oss cad to bim for cultural heritage digital representation. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLII-2/W3, 439–445. https://doi.org/10.5194/isprs-archives-xlii-2-w3-439-2017

López, J.L., Lerones P.M., Llmas J., Bermejo J.G.G., & Zalama E. (2018). A Review of Heritage Building Information Modeling (H-BIM). *Multimodal Technologies and Interaction 2*(2), 21*. MDPI AG.* https://doi.org/10.3390/mti2020021

Mammoli, R. (2021). *Paradigmi tecnologici per un nuovo approccio nella digital transformation del patrimonio culturale: BIM per una semantica dell'architettura storica*. Retrieved from https://hdl.handle.net/11566/289637

Mammoli, R., Mariotti, C., & Quattrini, R. (2021). Modeling the Fourth Dimension of Architectural Heritage: Enabling Processes for a Sustainable Conservation. *Sustenaibility, 13*(9), 5173-5188. https://doi.org/10.3390/su13095173

Murphy, M., McGovern, E., & Pavia S. (2009). Historic building information modelling (HBIM). *Structural Survey, 27*(4), *311–327).* https://doi.org/10.1108/02630800910985108

National Institute of Building Sciences (2017). National BIM Guide for Owners. https://www.nibs.org/files/pdfs/NIBS_BIMC_NationalBIMGuide

Osello, A., Barone, L., Davardoust, S., De Luca, D., & Del Giudice, M. (2016). La centralità della rappresentazione con il BIM. *DisegnareCON, 9*(16).

Pavan, A., Mirarchi, C., Cavallo, D., & De Gregorio, M. (2020). Standard BIM, il mondo dopo la ISO 19650. *Ingenio*. https://www. ingenio-web.it

Quattrini, R., Pierdicca, R., Morbidoni, C., & Malinvernia E. S. (2017). Conservation-oriented HBIM. the bimexplorer web tool. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLII-5/W1, 275–281. https://doi.org/10.5194/isprs-archives-xlii-5-w1-275-2017.

Quattrini, R., Battini, C., & Mammoli, R. (2018). HBIM to VR. Semantic awareness and data enrichment interoperability for parametric libraries of historical architecture. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLII*(2), 937-943. https://doi.org/10.5194/isprs-archives-XLII-2-937-2018

Simeone, D., & Cursi, S. (2016). The role of semantic enrichment in building information modelling. Technologies engineering materials architecture. *TEMA: Technologies, Engineering, Materials and Architecture*, *2*(2), 22-30. https://doi.org/10.17410/tema.v2i2.105 .