The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLVIII-M-2-2023
29th CIPA Symposium “Documenting, Understanding, Preserving Cultural Heritage:
Humanities and Digital Technologies for Shaping the Future”, 25–30 June 2023, Florence, Italy

A SCAN-TO-BIM PROCESS FOR THE MONITORING AND CONSERVATION OF THE ARCHITECTURAL HERITAGE: INTEGRATION OF THEMATIC INFORMATION IN A HBIM MODEL

A. Ferro [1], M. Lo Brutto [1, *], G.M. Ventimiglia [2]

[1] Department of Engineering, University of Palermo, Italy, (alessandra.ferro01, mauro.lobrutto)@unipa.it
[2] Department of Architecture, University of Palermo, Italy, gasparemassimo.ventimiglia@unipa.it

KEY WORDS: Scan-to-BIM, HBIM, Point Cloud, Parametric Modelling, Conservation, Decay.

ABSTRACT:

Conservation actions often challenge traditional planned conservation tools, especially when referring to the management of data relating to the existing building heritage due to the huge amount of information to be acquired and archived. In response to this requirement, the Building Information Modelling (BIM) process, applied to historical buildings as Historical-BIM (HBIM), could be an effective solution for integrating different types of data concerning not only the geometric features but also useful qualitative information in conservation and preservation works (i.e. the type of materials, construction techniques, the presence of degradation and instability, intervention techniques, etc.). Although the BIM process has reached a considerable level of maturity, several aspects related to the application of the method to existing structures through the Scan-to-BIM process require further research; particularly the need to find suitable approaches to integrate, manage and store thematic information. The article describes the work carried out in the case study of Villa Castelnuovo, an eighteenth-century architectural building located in Palermo (Italy), in which, starting from an integrated survey, it was possible to generate an HBIM model to support all the phases concerning preventive maintenance, long-term redevelopment and management of the architectural asset. The research focused mainly on the modelling and information integration phases, developing a procedure applicable to different contexts for storing, managing and analysing the external façade decay necessary for documenting and monitoring the architectural heritage.

1. INTRODUCTION

The maintenance of architectural heritage is one of the main challenges for contemporary society and one of the most important tasks for governments and local administrations to preserve architectural knowledge as a unique and irreplaceable source of aesthetic, historical and cultural values (Cursi et al, 2015). New and continuous solutions in the study and management of architectural heritage are therefore necessary to implement investigations for monitoring and risk prevention and to develop tools for protection. As reported by D’Ayala et al. (2008) "The success of the conservation of a historical building, complex or a city depends on its continued use, daily care and maintenance". This statement highlights the basic principle of preventive and planned conservation, with the aim of identifying research activities, as well as the development of new tools and techniques, to improve preventive conservation strategies.

The purpose of preventive conservation is the protection of the Cultural Heritage, implemented through actions aimed at maintaining the conditions of greater care and lower risk, foreseeing the arising of material degradation, to maintain the physical integrity and usability of the building heritage (Wirilander, 2012). Therefore, the preventive conservation approach requires sustained and long-term action to better manage cultural assets during their life cycle, resulting in specific monitoring plans (Adami et al., 2019).

The monitoring of architectural heritage is developed in the actions, carried out periodically or continuously, through measurement over time of certain parameters that influence the condition of the building, providing important information on the condition of the asset to foresee possible interventions. The possibility of managing the whole information related to the knowledge of an architectural asset is often a difficult task linked to the huge amount of data required and therefore to their management over time (Cursi et al., 2015)

Although several researchers have been interested in this topic, the multidisciplinary of the information has revealed the need to find an appropriate tool capable of managing and archiving data from different fields.

At the beginning of the 21st century, processes applied to the life cycle of buildings and civil infrastructure began to be reformulated towards a new representation technology based on the development of generative processes of Building Information Model (BIM); this methodology can also be applied to the digitization of the building heritage, allowing the improvement of numerous processes related to the management and monitoring of the historical-cultural heritage asset (Moyano et al., 2022). According to Dore and Murphy (2012), it is possible to obtain the so-called Heritage or Historic Building Information Model (HBIM) when this process is applied in the context of historic buildings. Starting from the HBIM methodology, in which each geometric element is linked to semantic information, it is possible to obtain a unified and easily manageable information system of the architectural heritage (Aricò et al., 2023).

In the case of HBIM process, it is frequent to talk about Scan-to-BIM approach, which is the process that, starting from a detailed survey of the object, allows to achieve the realization of its 3D model in the HBIM environment (Rocha et al., 2020; Allegra et al., 2020; Aricò and Lo Brutto, 2022). This methodology has been supported by advanced survey techniques and by the

* Corresponding author

development of new modelling tools starting from the point cloud (Costantino et al, 2021).
In this context, the research is not limited to the simple production of parametric 3D models, but to define the criteria and methods of Scan-to-BIM procedure for the creation of an HBIM model that supports all decision-making phases, including those related to maintenance, redevelopment and management of the asset. Although several researchers have approached the analysis of the BIM methodology applied to historical buildings, some gaps remain if we consider their specific features: on one side the materials and construction techniques and, on the other, the temporal dimension (Santoni et al., 2021). Furthermore, it is essential to find ways of representing thematic information through parametric BIM objects regarding materials, degrades, diagnostics and information on the development of the building or its previous restoration interventions (Delpozzo et al., 2022). Different solutions have been expressed in relation to these requirements, which differ according to the level of detail to be pursued, the specific characteristics of the case and the semantic structures available.
Regarding the problem of integrating information on façade decay, some researchers have proposed a solution in creating "filled region" to outline the forms of decay and instability, with a considerable advantage in the ease of execution and the possibility of creating legible thematic mappings. This procedure does not allow to extract quantities (such as perimeter and area) that can be used to define costs in case of restoration project (Santagati et al., 2021). Other researchers focus on the geometric representation of themes, modelling thin layers and superimposed layers on the model elements or focusing on the information part, linking decay information as parameters on the model objects (Matrone et al., 2020). A similar approach gives the possibility to enrich the database with graphic and geometric data that can be effectively used to design and manage future interventions. The advantage is the possibility to identify the state of conservation of the materials and the detailed description of the interventions necessary for the restoration of the building, converting the traditional CAD mapping in parametric BIM objects, using adaptive components (Malinverni et al., 2019).
Further experiments involve the method of stratigraphic representation of the walls, which starting from 2D entities such as orthophotos, can associate information directly on the model. Specifically, the procedure, implemented through specific software, associates each component with the corresponding orthophoto displayed through the implementation tools, through which the user can make mapping drawing polygons (Bruno et al., 2018).
In this work, an experimental methodology was developed through the application of the Scan-to-BIM process to historical architecture with the aim of integrating thematic information, capable of describing the state of conservation of the asset, with the geometric and semantic information of the HBIM model. The work was aimed at modelling the external façade decay of a historical complex proposing a solution to integrate this thematic information in the HBIM environment. In this way, information related to preventive conservation can be stored in the HBIM, giving tools that could be exploited by the different actors involved in the HBIM process. The study is also the starting point for identifying, modelling and managing the evolution over time of the external façade decay in an HBIM environment.
The complexity of data enrichment in the HBIM environment was solved by developing and testing a specific workflow using as a case study the "Villa Castelnuovo" in Palermo (Italy), a historical building, built in the 18th century.
The information regarding the types of decay, deriving from a critical analysis of the building, has been inserted into the HBIM model as a 3D parametric object, overcoming the logic of 2D mapping (Banfi et al., 2022).
The proposed iconography refers to the ICOMOS glossary published in 2003, in order to be able to refer to an international lexicon, thus facilitating the readability and interpretation of data. The HBIM model has resulted in an integrated archive, in which is highlighted the importance of ordinary maintenance operations in conservation and restoration activities, to improve the periodic monitoring operations of the building.

2. THE HBIM

The HBIM process is essential to obtain an intelligent model in which all the elements are linked to a database containing different semantic information, which can be constantly integrated with any information regarding conservation and restoration interventions, in an ever-evolving framework (Khan et al., 2022).
The application of this methodology is made possible thanks to the use of modern survey devices, to acquire useful data which form the basis for modelling a geometrically correct three-dimensional element (Rocha et al., 2020; Lo Brutto et al., 2021). In particular, the use of photogrammetry and terrestrial laser scanning techniques is essential to architectural surveys especially when these activities are related to conservation, and restoration projects (Bruno et al., 2022). Each method requires specific tools, involves complex re-processing and has its limits and advantages (Dore et al., 2015; Lo Brutto and Dardanelli, 2017) but frequently they are integrated to obtain the optimum result (Agnello and Lo Brutto, 2007; Vacanas et al., 2015; Lo Brutto et al., 2017).
The 3D survey guarantees the possibility of recording the current state of buildings with efficient, non-invasive, rapid and especially highly precise techniques, allowing more complete studies and more accurate interventions (López et al., 2018).
The steps that characterize the HBIM process can be summarized in the following points:

- data acquisition;
- data processing;
- parametric modelling;
- data integration.

The data acquisition phase involves several operations whose purpose was to acquire the greatest number of geometric and constructive information of the building which are fundamental for the consequent processing and drafting of the technical documents.
The geometric information was acquired through processed point clouds that can be incorporated into BIM platforms; the use of point clouds is a new paradigm for the design, documentation, and digital management of existing assets, especially of the built historical monuments (Akbarnezhad et al., 2014).
The creation of parametric models that correspond as much as possible to reality and the integration with semantic information of different natures is of fundamental importance so that the HBIM approach is exploited in all its potential (Mateus et al., 2019).
It is important to note that BIM platform libraries and tools focus on the design and construction of new buildings with simple, regular and standardized objects (Bryde et al., 2013). The heterogeneity and uniqueness of the existing building heritage, especially in historic buildings, due to the different interconnections of architectural styles and geometric transformations that have occurred over time, involves a complex process of knowledge, maintenance, management and often very articulated enhancement. For this reason, the detailed

reconstruction of the historical-cultural heritage has highlighted some limitations of BIM process, such as the unavailability of libraries of historical parametric objects and the lack of tools for managing the complex and irregular shapes obtained from point clouds (Allegra et al, 2020;). In the field of restoration, an HBIM system represents an effective tool for conservation and monitoring to prevent damage situations and is also advantageous for the analysis of degradation as part of the creation of thematic mapping (Malinverni et al., 2019).

3. THE CASE STUDY

The case study is the historical building of “Villa Castelnuovo” in Palermo (Italy), a neoclassical building founded in the second half of the 18th century by the will of Prince Gaetano Cottone as a summer residence. The building stands on a fourteen-hectare park, mostly cultivated with olive groves, citrus groves and annual crops. The park assumed a unique configuration if compared to the traditional art of Sicilian gardens of the time, in which the building appears centrally between the transversal axis and the straight avenue, formed by plots of cultivated land.
After the death of Prince Cottone in 1802, the building became the property of his son Carlo Cottone, Prince of Castelnuovo and Villahermosa, who wanted to transform the summer residence into an Agricultural Institute.
The project was entrusted in 1820 to the architect Antonio Gentile who, inspired by the neoclassical architecture of Palermo, modified the original project until its completion in 1829 with the current building called "Gymnasium".
The building rises on a rectangular base measuring about 19 x 40 metres and consists of two symmetrical parts connected by an open vestibule that constitutes the entrance to the Gymnasium. (Figure 1). Eight Doric columns, whose height is equal to five times the diameter of the base, are in the central part of the vestibule and support a hemispherical dome on pendentives. (Figure 2).

Figure 1. View of Villa Castelnuovo.

The building, consisting of two floors, is partly basement, being the lower floor placed within a rectangular moat of about 52 x 31 meters and 2.40 meters deep. The building, in squared stone, consists of an above-ground floor and a basement floor connected, internally by a spiral iron staircase, and externally by four flights of stairs on rampant arches, which allow you to pass the trench that surrounds the building.
The two main façades qualify as a sort of temple in antis, with the two columns and Doric entablature, in which there are the inscriptions "*Istituto Castelnuovo*" in the South-West façade, while "*Alla Sicula Agricoltura*" on the North-East façade, now no longer readable due to the high state of deterioration and neglect of the building.
The Agricultural Institute was inaugurated in 1847, operating for a little more than a century from that date, when, losing its original connotation, all activities ceased.
After the Second World War, Villa Castelnuovo became the property of the Sicilian Region, under the management of the IPAB (*Istituto Principe di Castelnuovo e Villahermosa*).
A part of the wide garden has been entrusted to the University of Palermo, which has placed some greenhouses.
In recent years the attention to the redevelopment and recovery of the historical memory of the complex and its garden has grown, despite this the building is in a high state of deterioration.

Figure 2. View of the central vestibule and the Doric columns.

4. DATA ACQUISITION AND PROCESSING

In the building’s 3D survey, different methods were carried out based on the specific needs to be pursued and the morphological and logistical conditions presented by the case.
Among the issues that emerged during the survey, we focused on the possible difficulties that could have been encountered in the connection between the main floor and the lower floor, and at the same time between the two lateral parts and the vestibule.
Following the on-site inspection, the strategy of the survey operations was established, in which the different successive phases are distinguished according to the work areas.
Laser scanning was used to acquire 3D data of the interior, while aerial photogrammetric techniques were used to acquire 3D data of the exterior part. In addition, for the acquisition of thematic information of the façades, useful for decay analysis, the survey was integrated through terrestrial photogrammetric acquisition.
The laser scanner survey was carried out using the Faro Focus 3D S120 device, planning an acquisition scheme that considered the various criticalities above all the connection between exterior and interior, main and lower floor.
The survey of the interior was carried out by placing the laser scanner in the centre of the rooms, where this was possible, and near the connecting areas (in the openings between one room and another). The only factor that limited some operations was the state of deterioration and abandonment of some rooms, which, in some cases, compromised the possibility of carrying out the overall survey of these environments.

At the end of the scan of the interior, the connection between the two floors was ensured by the two internal staircases (Figure 3). For the external part, however, it was necessary to find a way to create a connection that lead back to the part of the vestibule, this solution was provided by placing the instrument in the two landings of the external staircase of the North façade (Figure 4).

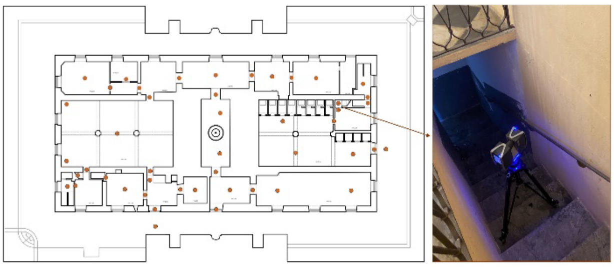

Figure 3. Scheme of scan points: scan of the internal staircase.

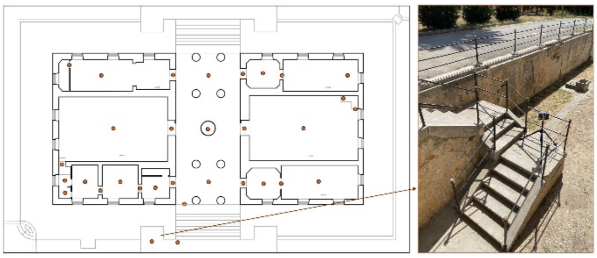

Figure 4. Scheme of scan points: scan of the external staircase.

To complete the survey of the roof and the external façades, an aerial photogrammetric survey using a DJI Mavic Mini drone was performed. The aerial photogrammetric survey was planned and executed with a nadiral flight along the roof and two circular flights with a camera tilted along the four façades. In addition, it was considered appropriate to integrate these data with a terrestrial photogrammetric survey, to obtain images of the façades with a high level of detail; this survey was carried out using the Canon Eos 1100D digital camera, according to three different capture schemes shown in Figure 5.
Autodesk's ReCap Pro software was used to process the point clouds measured with the Faro Focus 3D laser scanner, dividing the work into two projects relating to the scans made for the interior spaces of the main floor and another for those of the lower floor.
The first processing step was the automatic registration of scans, as well as the manual registration of individual scans where the automatic process failed. For scans that did not align automatically, manual registration was done using common points between two scans. In all cases, manual registration was further improved with automatic registration.
Once the registration was completed, the overall point clouds were merged and subsequently filtered and resampled by setting a maximum distance between the points of 0.01m; in this way, we obtained a remarkable reduction in number of the points (from about 213 million points to about 42 million points) without losing the very high level of detail of the data.
Agisoft Metashape software was used for photogrammetric processing. A unique photogrammetric project was carried out using drone and terrestrial images. The images were oriented using some ground control points measured on the façades by means of a topographic survey. Some ground control points were used as check points, for the effective control of accuracy; centimetric values were obtained for the check points.

After image orientation, an overall point cloud of the external parts of the building was obtained (Figure 6). This point cloud had about 22 million points and an average resolution of about 0.003 m. The photogrammetric processing was also aimed to calculate the orthophotos of the façades. For this process, only the terrestrial images, that had a better resolution, were considered.

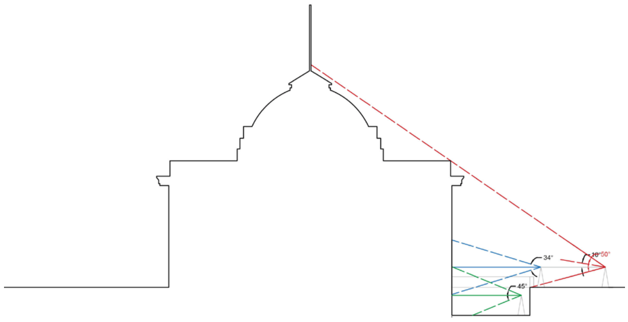

Figure 5. Scheme of the terrestrial photogrammetric survey.

Figure 6. Point cloud of the external parts of Villa Castelnuovo.

After the first phases of processing, it was necessary to align the point cloud of the interior, obtained from the laser scanning survey, and the point cloud of the exterior obtained from the photogrammetric survey in order to put the entire dataset into the same reference system and to overlap the two point clouds. This last step was done applying a Cloud-to-Cloud registration with the CloudCompare software; a first alignment was performed by choosing equivalent point pairs in both entities, an automatic alignment with ICP algorithm was carried out to improve the result. This process was possible because scans of one of the main façades has been acquired during the laser scanner survey. This part was therefore in common between the two datasets. In this way, the laser scanner point cloud resulted in perfect overlap with the photogrammetric one. The two datasets were merged obtaining a final point cloud of about 65 million points. Once all the available information were collected, the overall point cloud was imported into the Recap Pro software to be used as the basis for parametric modelling in the HBIM environment using Revit Autodesk's software.

5. DATA MODELLING

The modelling has necessarily dealt with different problems related to the application of the HBIM process in a building of historical/architectural heritage, in which the requirement is to obtain a reliable and accurate model.

The model is composed of parametric objects, i.e. components of virtual buildings identified by modifiable parameters, such as dimensions; these virtual objects may also contain other types of data, such as non-metric information relating to materials, decay, and construction techniques.
Although the Revit software has many predefined families, that define the parametric objects, these families often do not satisfy the different needs, especially regarding historic buildings where the unique and irregular elements challenge the standardized logic of BIM libraries.
The essential architectural elements such as walls, floors and roofs, have been modelled in a simplified way using the “system parametric families” provided by the software, while the unique elements, typical of this historical architecture, have been modelled through the generation of “in place parametric families” (e.g. columns, cruciform pillars, hemispherical dome, vaults).
The modelling has allowed the development of a high-quality 3D model, as the most likely re-proposal of the building being studied, through which it was possible to condense all the information necessary for the definition of the asset (Figure 7).

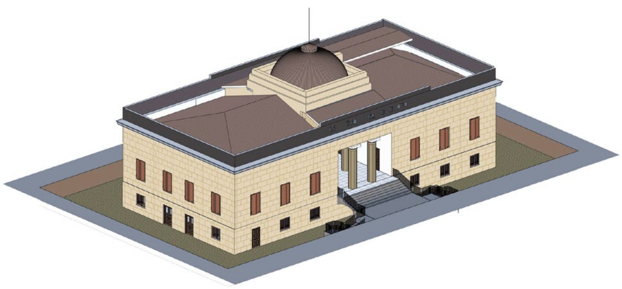

Figure 7. HBIM model of Villa Castelnuovo.

6. THE DECAY MAPPING

The correct planning of any recovery, maintenance or restoration intervention requires in-depth preliminary checks; for this reason, was conducted a critical-descriptive analysis in situ, to understand and identify possible causes of deterioration.
From the in-situ analysis it emerged that the building has undergone some minor interventions over time, however, it faces several issues regarding the deterioration of the materials, due to different causes.
The analysis showed that the masonry consisted of an ivory-coloured plaster with three-layer lime mortar worked with false ashlars, due to atmospheric agents, has degraded over time, causing the presence of chromatic alterations in several zones; in the basement part, however, there are problems related to humidity due to the capillary rise of the water present in the ground. The same problem is found in almost all the masonry with a visible presence of efflorescence phenomena, due in this case to the localized leaks of the disposal systems placed inside the masonry.
The upper part, especially that of the modelling, is interested in moisture infiltration that, due to direct contact between the wall surface and water, has led to the presence of grey-green spots which suggest the presence of biological patina.
However, the decay is not limited to the stone elements, it also affects the wooden and metal elements, in which there are problems related, as regards wood, the absence of the protective film and the presence of small circular holes that suggest a biological attack in place, while oxidation for metallic elements.
Once the recognition of the decay has been completed, the mapping of the latter was drawn up to classify homogeneously the visible manifestations of decay considering also those referring to the same pathology that manifests themselves differently for the heterogeneity of the material support.
The study was first concerned to the South-West façade of Villa Castelnuovo (Figure 8), which appeared to be the most compromised; then the procedure was extended to all the other façades of the building. This step was the basis for increasing the knowledge and expanding the information of the building.
Using the orthophotos it was possible to obtain the supporting documentation for mapping the decay; this information has been integrated into the mapping referring to the international ICOMOS glossary released in 2003 (Figure 9).
The classification of the existing decay has highlighted the possibility of implementing this data within the HBIM model, to create a complete information model to improve interventions on the state of conservation of the building.
These investigations are indispensable for the recognition of the causes that have led to the formation of degradation, establishing a reliable documentation to provide further analyses and interventions for the preservation of the asset.

Figure 8. Orthophoto of South-West façade.

Figure 9. Decay mapping on South-West façade.

7. INTEGRATION OF THEMATIC INFORMATION IN THE HBIM MODEL

Once the information relating to the current state of the building was obtained, the research focused on the possibility of integrating this information within the BIM model. This ensures the possibility of combining and comparing the different data in a format that is readable and accessible by different scientists and experts, improving the conservation and maintenance processes of the complex.
The aim is to develop a strategy that can exploit the potential of HBIM even for less conventional activities, given that no specific categories are included for decay.
Although several researchers have focused on the possibility of adding this information through the 2D representation to which it is possible to associate a type of decay/deterioration, these cannot be enriched with any type of parameter, thus not providing any development in the BIM tools (Delpozzo et al., 2022).
For this reason, it was chosen to map the decay within the model in three-dimensions, trying to move from a two-dimensional logic to a three-dimensional one. This solution guarantees the possibility of enriching the database with parameters relating to geometric, alphanumeric and graphic data, which can describe the state of conservation and any interventions necessary for the restoration of the building.
For this purpose, the creation of specific “loadable parametric families”, that adapts to the different surfaces through the insertion of adaptive vertices, was proposed. This type of family

can take on different shapes based on the surfaces on which it is placed, making the method repeatable and usable in other contexts as well.
Specifically, the generic adaptive parametric modelling is based on adaptive points that allow to create polygons and geometric shapes according to the different forms, overlapping the elements in space.
Through the "Generate shape" tool, it was also possible to create parametric objects, which can be modified at any time, in order to obtain an element with a minimum thickness to be placed on the wall surface (Figure 10). The points were inserted in the space following a specific direction, adding several vertices such as to ensure the possibility of outlining any type of decay.

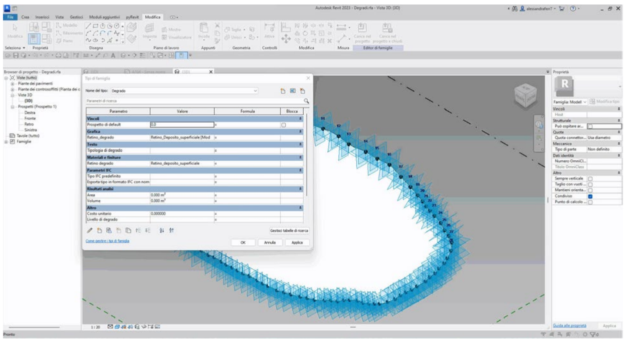

Figure 10. "Generate shape" tool interface.

Through the parameterization of decay, it was possible to assign additional parameters to those present by default, in which the following items were inserted:

- type of decay, in which the characteristics of the alteration suffered by the material have been specified;
- degradation material, in which it is possible to create new materials where it is possible associate the material with the ICOMOS nomenclature;
- area, the extension of the decay;
- unit cost, the cost of the possible intervention per square metre;
- total cost of the intervention based on the extent of degradation.

The family created is then imported into the project, and duplicated according to the different types of decay identified in the case study. In this way for each type of decay, it is possible to collect a series of information such as to specifically define each current pathology.
The possibility of reproducing the mappings on the model as faithfully as possible to reality was guaranteed by the inclusion in the sectional view of the mapping, carried out on orthophotos, in this way it was possible to draw the outline of the present degradation by inserting the adaptive points following the geometry shown from the elaborate, which served as a guideline (Figure 11).
Furthermore, in Revit it is possible to assign an identification code to each parametric element; every code is associated with information that are not purely geometric, but rather concerns the type of deterioration, type of intervention, cost of the intervention, materials and detailed images of the degradation, etc. Therefore, by selecting an element identified in the model, the characteristics can be displayed directly within an abacus, knowing all the different characteristics suitable for describing it (Figure 12).

Within the BIM process it is possible to draw up the executive tables in which to insert the mapping of the current state of the building and any planned maintenance interventions, facilitating and simplifying the management of the restoration operations, constituting a single archive that can be consulted by different experts. The mapping follows the legend of the ICOMOS international glossary, in which a colour is associated with each different type of decay, thus providing a simplified and immediate reading of the state of the Villa Castelnuovo, which will finally associate the relative legend in the hypothetical project table (Figure 13).
The 3D modelling of degradations within the HBIM platform involves the enrichment of databases that can be effectively exploited to manage future interventions in the field of maintenance and restoration (Figure 14).

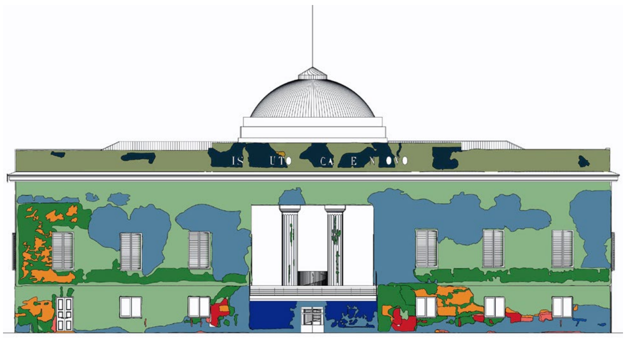

Figure 11. Section view of degradation mapping in the HBIM model.

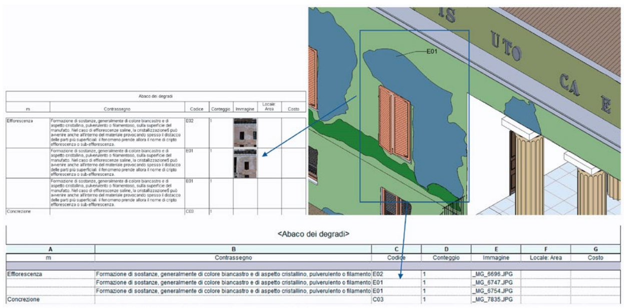

Figure 12. Graphical interface inserting identification code and its abacus.

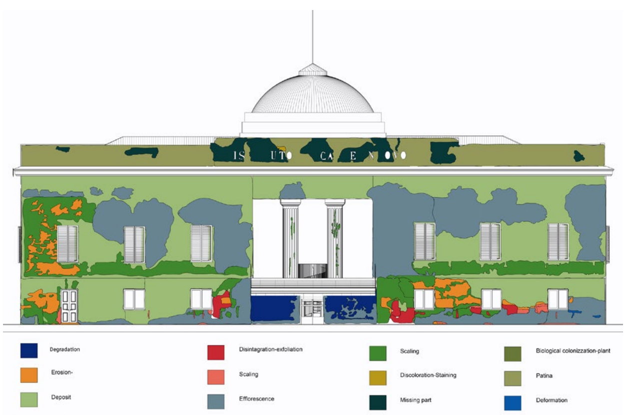

Figure 13. Conservation project table in the Revit software.

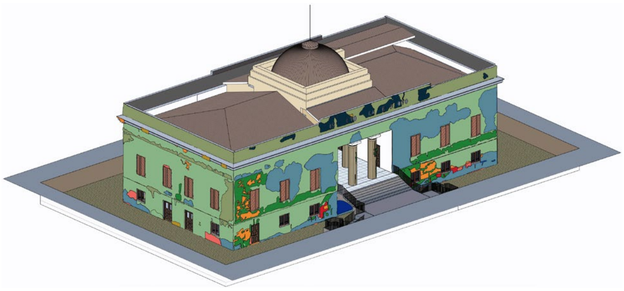

Figure 14. Decay mapping in the HBIM model.

8. CONCLUSIONS

The work shows the possibility to use the HBIM process in cultural heritage preservation as an effective solution to support possible conservation and restoration projects.
In particular, the Scan-to-BIM process made it possible to lay the appropriate foundations for further experimentation phase which envisaged new solutions for integrating and sharing information within the HBIM model itself.
The aim was to plan a new strategy that can exploit the benefits of HBIM for less conventional activities such as, in the present case, the mapping of degradations, but which can be extended to other fields.
Through several tests, a 3D parametric representation was investigated and proposed with the aim of highlighting how a historic building can also be digitized in geometric elements that do not correspond to architectural and structural elements.
The possibility of associating an identification code to each element which identifies attributes such as the type of deterioration of the material, the possible intervention and cost, allows to obtain a single easily consultable and interoperable model, which simplifies the management of any restoration phases.
In addition, further analysis must be sought in the potential of HBIM systems, connected to the possibility that the database linked to the model can improve knowledge, such as the possibility of monitoring the evolutions that these diseases have undergone over a wider period.
However, the process still involves the use of many tools, processing times and software that, if not mastered with awareness, can lead to an exponential dispersion of information and the consequent loss of the high level of detail that historic buildings require.
The future challenge will be developments to further simplify the integration of this data and their sharing starting from the survey to more advanced forms of virtual sharing.

ACKNOWLEDGEMENTS

The authors are grateful to IPAB (*Istituto Principe di Castelnuovo e Villahermosa*) of Palermo who allowed the surveys and to Emanuele Iuculano for providing the UAV flight.

REFERENCES

Adami, A., Fregonese, L., Rosignoli O., Scala, B., Taffurelli, L., Treccani, D., 2019. Geometric Survey Data and Historical Sources Interpretation for HBIM Process: the Case of Mantua Cathedral Façade. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLII-2/W11, 29–35, https://doi.org/10.5194/isprs-archives-XLII-2-W11-29-2019.

Agnello, F., Lo Brutto, M., 2007. Integrated surveying techniques in cultural heritage documentation. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XXXVI-5/W47, 1-6.

Allegra, V., Di Paola, F., Lo Brutto, M., Vinci, C., 2020. Scan-to-BIM for the management of Heritage Buildings: The case study of the Castle of Maredolce (Palermo, Italy). *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLIII-B2-2020, 1355–1362. https://doi.org/10.5194/isprs-archives-XLIII-B2-2020-1355-2020

Akbarnezhad, A., Ong, K.C.G. 2014. Chandra, L.R. Economic and environmental assessment of deconstruction strategies using building information modeling. *Autom. Constr.*, 37, 131-144, https://doi.org/10.1016/j.autcon.2013.10.017.

Aricò, M., Lo Brutto, M., 2022. From Scan-to-BIM to Heritage Building Information Modelling for an ancient Arab-Norman church. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLIII-B2-2022, 761-768, https://doi.org/10.5194/isprs-archives-XLIII-B2-2022-761-2022.

Aricò, M., Lo Brutto, M., Maltese, A., 2023. A Scan-to-BIM Approach for the Management of Two Arab-Norman Churches in Palermo (Italy). *Heritage*, 6, 1622-1644. https://doi.org/10.3390/heritage6020087

Banfi, F., Brumana, R., Landi, A. G., Previtali, M., Roncoroni, F., and Stanga, C. 2022: Building archaeology informative modelling turned into 3D volume stratigraphy and extended reality time-lapse communication. *Virtual Archaeology Review,* 13(26), 1–21. https://doi.org/10.4995/var.2022.15313

Bryde, D., Broquetas, M., Volm, J.M., 2013. The project benefits of building information modelling (BIM). *Int. J. Proj. Manag.* 2013, 31, 971-980, https://doi.org/10.1016/j.ijproman.2012.12.001

Bruno, N., Roncella, R., 2018. A Restoration Oriented HBIM System for Cultural Heritage Documentation: the case study of parma cathedral. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci*., XLII-2, 161-168. https://doi.org/10.5194/isprs-archives-XLII-2-171-2018.

Bruno, N., Mikolajewska, S., Roncella, R., Zerbi, A., 2022. Integrated processing of photogrammetric and laser scanning data for frescoes restoration. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.,* XLVI-2/W1-2022, 105-112. https://doi.org/10.5194/isprs-archives-XLVI-2-W1-2022-105-2022.

Costantino, D., Pepe, M., Restuccia, A., 2021. Scan-to-HBIM for conservation and preservation of Cultural Heritage building: the case study of San Nicola in Montedoro church (Italy). *Applied Geomatics*. https://doi.org/10.1007/s12518-021-00359-2

Cursi, S., Simeone, D., Toldo, I., 2015. A semantic web approach for built heritage representation. *In: G. Celani, D.M. Sperling, J.M.S. Franco (Eds.), 16th International Conference, CAAD Futures 2015*, July 8–10, 2015, São Paulo, Brazil, 383-401. doi.org/10.1007/978-3-662-47386-3.

D'Ayala, D., Fodde, E., 2008. Structural Analysis of Historic Construction: Preserving Safety and Significance. *Two Volume Set: Proceedings of the VI International Conference on Structural Analysis of Historic Construction, SAHC08*, 2-4 July 2008, Bath, United Kingdom (1st ed.). CRC Press.

Delpozzo D., Treccani D., Appolonia L., Adami A., Scala B., 2022. HBIM and Thematic Mapping: Preliminary Results, *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLVI-2/W1-2022, 199–206, https://doi.org/10.5194/isprs-archives-XLVI-2-W1-2022-199-2022.

Dore C., Murphy M., 2012. Integration of Historic Building Information Modeling (HBIM) and 3D GIS for recording and managing cultural heritage sites. *18th Int. Conference on Virtual Systems and Multimedia*, Milan, Italy, 369-376, doi: 10.1109/VSMM.2012.6365947.

Dore, C., Murphy, M., McCarthy, S., Brechin, F., Casidy, C., Dirix, E., 2015. Structural simulations and conservation analysis historic building information model (HBIM). *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci*., XL-5/W4, 351-357, https://doi.org/10.5194/isprsarchives-XL-5-W4-351-2015, 2015.

Khan, M.S., Khan, M., Bughio, M., Talpur, B.D., Kim, I.S., Seo, 2022. An Integrated HBIM Framework for the Management of Heritage Buildings, *Buildings,* 12, 7, 964, https://doi.org/10.3390/buildings12070964.

Lo Brutto, M., Dardanelli, G., 2017. Vision metrology and Structure from Motion for archaeological heritage 3D reconstruction: a Case Study of various Roman mosaics. *ACTA IMEKO*, 6 (3) 35-44, https://doi.org/10.21014/acta_imeko.v6i3.458

Lo Brutto, M., Sciortino, R., Garraffa, A., 2017. RPAS and TLS techniques for archaeological survey: the case study of the archaeological site of Eraclea Minoa (Italy). *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLII-2/W3, 433-438, https://doi.org/10.5194/isprs-archives-XLII-2-W3-433-2017.

Lo Brutto, M., Iuculano, E., Lo Giudice, P., 2021. Integrating topographic, photogrammetric and laser scanning techniques for a Scan-to-BIM process. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.,* XLIII-B2-2021, 883-890. http://dx.doi.org/10.5194/isprs-archives-XLIII-B2-2021-883-2021

López, F.J., Lerones, P.M., Llamas, J., Gómez-García-Bermejo, J., Zalama, E., 2018. A Review of Heritage Building Information Modeling (H-BIM). *Multimodal Technol. Interact,* 2, 21, https://doi.org/10.3390/mti2020021.

Malinverni, E.S., Mariano, F., Di Stefano, F., Petetta, L., Onori, F., 2019. Modelling In HBIM to document materials decay by a thematic mapping to manage the Cultural Heritage: the case of "Chiesa Della Pietà" in fermo. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci*., XLII-2/W11, 777-784, https://doi.org/10.5194/isprs-archives-XLII-2-W11-777-2019, 2019.

Mateus, L., Fernández, J., Ferreira, V., Oliveira, C., Aguiar, J., Gago, A. S., Pacheco, P., and Pernão, J, 2019. Terrestrial laser scanning and digital photogrammetry for heritage conservation: Case study of the historical walls of Lagos, Portugal. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.,* XLII-2/W11, 843-847, https://doi.org/10.5194/isprs-archives-XLII-2-W11-843-2019.

Matrone, F., Lingua, A., Pierdicca, R., Malinverni, E., Paolanti, M., Grilli, E., Remondino, F., Muriyoso, A., Landes, T., 2020. Un benchmark per la segmentazione semantica di nuvole di punti di beni culturali. *Bollettino della società italiana di fotogrammetria e topografia*, 1 (dic. 2020), 10–18.

Moyano J., Carreno Euan E., Nieto J., Gil-Arizon I., Bruno S., 2022. Systematic approach to generate Historical Building Information Modelling (HBIM) in architectural restoration project. *Automation in Construction*, 123 https://doi.org/10.1016/j.autcon.2022.104551.

Rocha, G, Mateus, L, Fernández, J, Ferreira, V., 2020. A Scan-to-BIM Methodology Applied to Heritage Buildings*. Heritage*, 47-67. https://doi.org/10.3390/heritage3010004

Santagati, C., Papacharalambous, D., Sanfilippo G., Bakirtzis, N., Laurini, C., Hermon, S., 2021. HBIM approach for the knowledge and documentation of the St. John the Theologian cathedral in Nicosia (Cyprus). *Journal of Archaeological Science: Reports*, 36, 102804, https://doi.org/10.1016/j.jasrep.2021.102804

Santoni, A., Martín-Talaverano, R., Quattrini, R., Murillo-Fragero, J. I., 2021. HBIM approach to implement the historical and constructive knowledge. The case of the Real Colegiata of San Isidoro (León, Spain). *Virtual Archaeology Review*, 12(24), 49-65. https://doi.org/10.4995/var.2021.13661.

Vacanas, Y., Themistocleous, K., Agapiou, A., Hadjimitsis, D., 2015. Building Information Modelling (BIM) and Unmanned Aerial Vehicle (UAV) technologies in infrastructure construction project management and delay and disruption analysis. *SPIE Proceedings*, 9535, 93-103, https://doi.org/10.1117/12.2192723.

Wirilander, H., 2012. Preventive Conservation: a Key Method to Ensure Cultural Heritage's Authenticity and Integrity in the Preservation Process*. e-conservation magazine,* 6(24), 32-44.