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HBIM for restoration project and data management of a religious complex

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Abstract **– The paper presents the first results of a research project aimed at digitizing the restoration process of the monastic complex of Santa Maria a Graiano, located in Fontecchio (AQ). The parametric model allows the management of heterogeneous data derived from multidisciplinary knowledge processes and facilitates data sharing. The representative modelling of the artefact after the damage caused by the 2009 earthquake, to which the planned restoration operations were linked, compared to the parametric model of the artefact after restoration, allowed cooperation between different professionals, in addition to the documentation of the work carried out. In this way, the model assumes a central role in the knowledge process but also the heritage management process as it facilitates the choice of conservation strategies to be implemented on the asset in future years and to preserve the memory of the interventions carried out, simplifying the maintenance process in the as-built phase.**

I. INTRODUCTION

Technological progress with developments towards the interconnection between information systems and physical objects, together with the address to the digitization of multiple processes and actions ranging from citizen services to entertainment, are increasingly directing the world of research towards digital management of cultural heritage in its several aspects. In this context, the organization of heritage maintenance, consolidation and restoration actions can also benefit from digitization by increasingly moving towards e-conservation processes [1].

The research presented in this paper is integrated into a larger project realized in collaboration with the Regional Secretariat of Abruzzo. The partnership aims to provide technological support through digital data management, the restoration process of the monastic complex of Santa Maria a Graiano, a monastery located in the municipality of Fontecchio in the province of L'Aquila and today in a state of abandonment and degradation (Fig. 1).

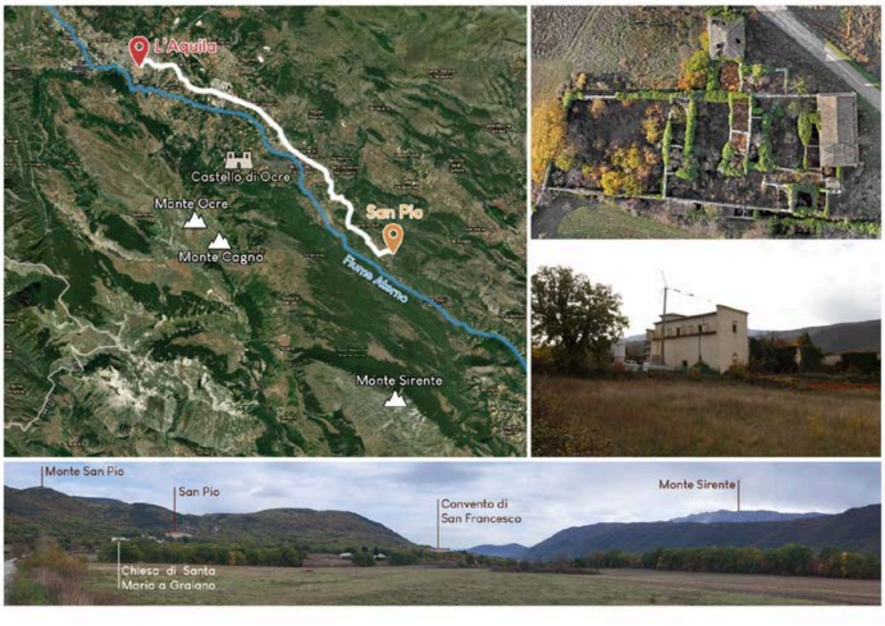

Fig. 1. The monastic complex of Santa Maria a Graiano and its territorial location.

Digital management of knowledge process, through the use of the parametric environment that has taken place after the integrated survey, is the challenge that the research project aims to address. To achieve this goal 3D model in a parametric environment was chosen, recognizing the BIM process's ability to represent multi-data, geometric and informative, in a qualitatively meaningful manner and with a high level of accuracy.

II. BACKGROUND

The scientific community has long since identified the HBIM paradigm as a suitable tool for the collaborative management of information relating to existing structures, which has been extended in the field of conservation also to reinforced concrete buildings that are part of the built heritage [2], for which it is possible to plan maintenance and restoration activities, as well as to track the building's state of conservation over time and assess the effects of any alterations on the structure.

The process of using a scan-to-BIM approach to develop parametric models of historic buildings to represent the geometry of artefacts, enriching it with the integration of non-geometrical data and thus semantization into a knowledge-based workflow whose aim is to share this data with conservation specialists is now considered well-established [4]. One of the potentials of HBIM procedures is its ability to concentrate a large variety of heterogeneous data representative of the complexity that characterizes the built heritage in a single environment [4]. In literature, information management's topic within HBIM has been extensively addressed concerning data management to facilitate decision-making in preventive and planned conservation. If parametric modelling is combined with algorithmic modelling, it is possible to increase the levels of detail and reliability even to the knowledge of the historic built environment and thus to the design of restoration and asset management interventions [5]. Some more recent experiences have gone as far as translating qualitative data into numerical values to define a priority index for interventions [6] or deploying visual programming (VPL) as a tool to support the HBIM methodology, for example, for calculating the Masonry Quality Index, a parameter used for the seismic analysis of masonry [7]. For some time now, the scientific literature has recognized the application of the Digital Twin (DT), which sees the HBIM environment as a suitable tool to support site managers in the preventive conservation of the built heritage, as well as an environment aimed at predicting threats to site integrity and the corresponding preventive solution on the basis of the analysis and simulations of data acquired from on-site sensors [8], testing it also on historical infrastructure [9].

III. THE BIM FOR THE RESTORATION OF THE CHURCH OF SANTA MARIA A GRAIANO

A. The case study

Santa Maria a Graiano is an architectural complex located in a rural setting in the municipal area of Fontecchio. The artefact consists of several buildings: the ancient rooms of the monastery, now in a state of ruins, and the church with some annexed chapels. The long evolutionary history of the architectural complex [10], intertwined with the historical and political events of Fontecchio and the city of L'Aquila, as well as the religious events that lasted until the suppression of the monastic orders in the 19th century, together with the seismic history of the place, have contributed to its current conformation and to the assignment of its cultural asset value.

The 2009 earthquake severely damaged the surviving structures to the extent that it was necessary to plan the restoration by dividing the operations into allotments of contracts. Consolidation and restoration of the chapels attached to the church are currently underway. One of these chapels is the subject of the present work: the one located between the church and the tower, which was severely damaged, and had its roof completely collapsed.

B. The BIM for restoration data management

Before proceeding to geometric modelling, the artefact analysis was implemented to understand the nature of each element that makes up the factory. This analysis was preparatory to the definition of the most appropriate procedures to be adopted in the artefact modelling phase, declining them on the basis of the problems encountered in the digital representation of structures pertaining to the cultural heritage.

The parametric model was structured in levels with varying degrees of detail that will gradually be implemented in relation to the restoration work phases. For this reason, the church and chapels have been better defined, while the buildings constituting the monastery complex have only been reproduced in their essential geometries (Fig. 2).

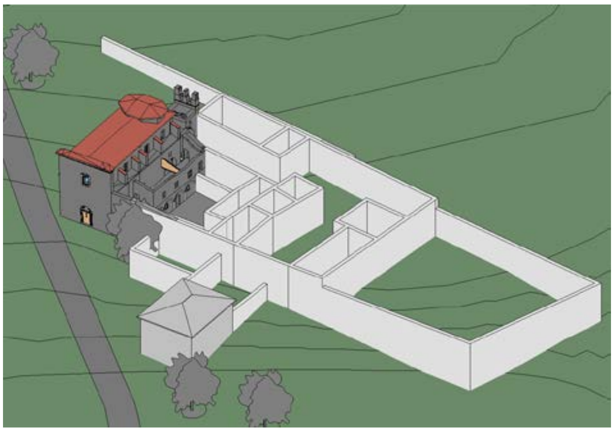

Fig. 2. The H-BIM of the modelled monastery with different levels of definition.

With regard to the chapel located between the church and the tower, which was the object of the restoration site of the first funded lot, various procedures were adopted, beginning with the modelling of the state of facts before the restoration work to arrive at the parametric modelling of the reconstructed and restored parts (Fig. 3).

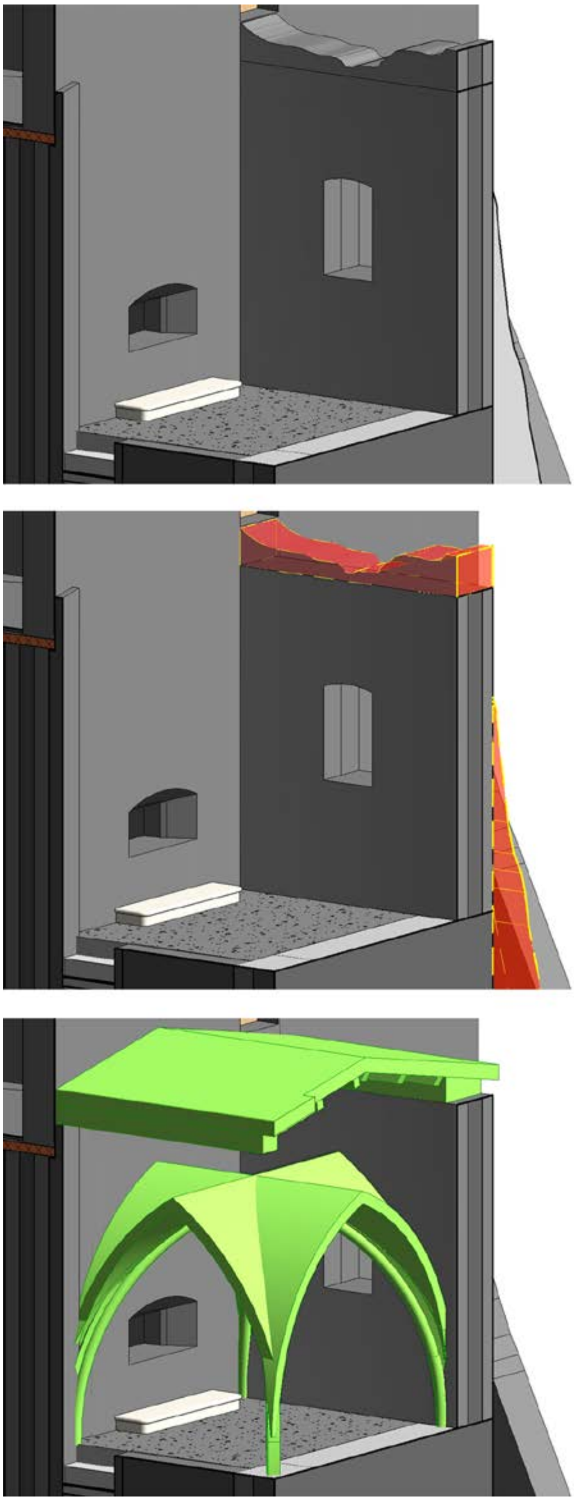

Fig. 3. View of the HBIM model of the chapel: the model of the state of the building before restoration, data management with the demolition phase and post-intervention model.

In the first modelling phase, the chapel was reproduced with the relative degradation and cracks, parametrically modelling the collapses and defects recorded on the masonry surfaces. Degradation and decay were implemented directly in the three-dimensional environment by resorting to the creation of new adaptive parametric families, which offer the possibility of modelling surfaces or polylines in support of wall elements by exploiting the properties of adaptive points (Fig. 4).

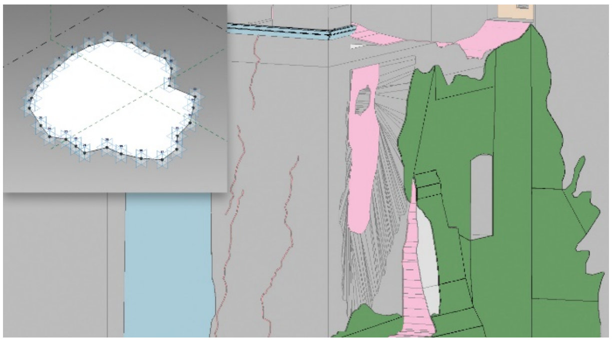

Fig. 4. Three-dimensional decay with adaptive family

When the insertion of these objects was particularly difficult due to the geometric complexity of the host elements, the use of in-place models was used. Information was associated with each modelled entity as such as technical drawings in pdf or jpg format with hyperlinks. Damaged masonry, superfetation and decay removal information was entered through the definition of the phases with the 'demolition' command.

At the same time as the reconstruction of the building, digitization steps were implemented, which led to the definition of a new model exploitable through time management in the parametric environment. The planned and realized works were also replicated in the model, as in the case of the reconstruction of the roof and the cross vault. The model was intended as a tool for linking and supporting the operators and documenting the restoration works, and all information was linked topologically to the three-dimensional representation (Fig. 5).

The cross vault of the chapel, the result of the reconstruction work, was processed with different levels of detail.

The first model was designed in a simplified way, with the purpose of providing geometric-formal information; a second model, on the other hand, was made in more detail, both in the geometric modelling phase, reproducing the single parts of the architectural elements, and in the definition of more enriched information. The broadening of the latter was possible thanks to the introduction of new parameters concerning the specific dimensions of single elements, their construction materials and related mechanical properties, estimated according to standards for existing elements and specific for new materials. In addition, pictures made in the construction worksite phase, useful for understanding the placement of the different components, have been linked for each parametric element.

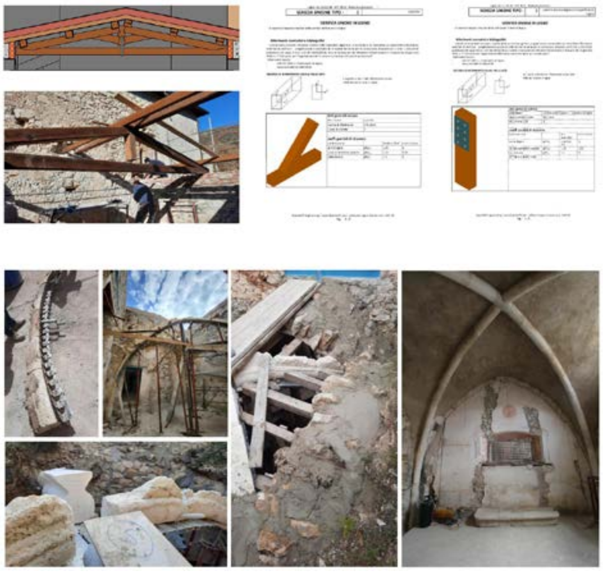

Fig. 5. Textual, graphic and photographic information linked to the model of the chapel after restoration.

All of this usable information within the parametric model and typologically linked to individual elements makes it possible to preserve the restoration work memory and to visualize it quickly in three-dimensional and graphical form. This mode of data management and fruition can facilitate the future preservation of the artefact by allowing the cross-checking of data before preparing material operations on the asset.

With regard to the ribs of the cross vault (Fig. 6), modelling was preliminarily carried out considering the rib as a single element and associating the information related to its reconstruction. As the level of detail increased, the individual rib was subsequently modelled following the configuration, indicative of the technological and construction process adopted, i.e., digitizing the individual ashlars to which the relative parameters were associated.

The first model documents the reconstruction process by anastylosis as a whole, while the second allows the identification of the original ashlars from the reintegrated ones.

Fig. 6. View of the simplified model of the chapel and one with a greater level of detail.

IV. DISCUSSIONS

Although some problems were highlighted in the modelling phase, absolutely in line with the difficulties of cultural heritage modelling, the results confirm the effectiveness of the parametric model in the digital documentation of the restoration works carried out on the architectural asset and in the management of the conservation actions adopted.

It was decided to test the effectiveness of a simplified model for restoration process managing to find a solution to the problem of modelling time for a historic building, as these are very high even with a highly trained operator and a high-performance computer. Therefore, the two models were compared with each other to assess their actual usefulness in the management and exchange of data in the current restoration context.

The simplified model also fulfills the function of documentation and data management before and after the restoration, but is less functional in the operational phase. Although this model also contains all the information in images and tables, it is less intuitive and more time-consuming in the data analysis phase. In contrast, the model created with a greater Level of Detail allows the immediate visualization of the restoration work through the precise query of individual architectural elements.

Despite slight differences, both models were functional: the first for project data management and the second for the punctual visualization of the operations and features of elements used during the restoration.

The model thus structured allowed the sharing of multi-data between professionals involved in the design and execution process of the restoration, as well as the management of cultural heritage and the documentation of interventions, essential operations for the restoration of assets with high cultural value.

In addition, the diversified visualization ranging from homogeneous colors to photorealistic textures, obtained by implementing the 3D model with the results of the photogrammetric survey, ensures the dissemination of the data to technicians and a broader public simultaneously.

V. FINAL REMARKS AND FUTURE PERSPECTIVES

The work again highlights how BIM is a valuable tool for restoration planning, digital documentation and management of the data associated with the implemented interventions.

The main problems encountered during the modelling phase are mostly related to the nature of the artefact, that is an asset of built heritage made up of different buildings and different construction features, result of the skills of several workers and actions over time that have contributed to the construction of the monastery complex as we see it today. The challenges involved in modelling walls built with different alignments and out-of-square, caused by reconstructions, redesigns and modifications of the building, or vaults laying on pre-existing masonry, made the model very close to its physical counterpart.

The implementation of the level of detail for the chapel's structural and non-structural elements, the definition of the mechanical parameters of the materials and the link with the data form the basis for the realization of a virtual replica that can fulfil different functions, for example the structural analysis or the creation of a digital twin capable of facilitating the maintenance operations of the architectural asset. Furthermore, the ongoing research aimed at implementing the model with the results of the restoration work in progress, at the same time as the data of physical actions planned for the remaining lots of the architectural complex, will favor the experimentation of new approaches to modelling, resorting to generative and algorithmic modelling, also with the aim of evaluating the pros and cons of the two methodologies.

Finally, the potential of the parametric environment can be enhanced through digital training for stakeholders in the territories, who are often involved in the day-to-day management of cultural heritage to ensure its preservation. These could benefit from the digital models capable of supporting them in the planning phase of interventions and their practical realization.

VI. CREDITS

Although the paper was shared and conceived jointly by the authors, Ilaria Trizio wrote paragraphs 1 and 2, Francesca Savini wrote paragraphs 3.A, 4 and 5, Federica Miconi wrote paragraph 3.B. The study illustrated here was carried out as part of the related activities foreseen in the Operational agreement between the Regional Secretariat for Abruzzo of the Ministry of Culture and the National Research Council, Institute for Construction Technology in L'Aquila. The present study has been carried out in the framework of the CTE SICURA, House of the Emerging Technologies in L'Aquila project.

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