Archaeology of buildings and HBIM methodology: integrated tools for documentation and knowledge management of architectural heritage

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***Abstract*—The research described in this paper illustrates the results of an investigation procedure that integrates different tools and methods, conducted to generate a parametric model starting from the results of the archaeological analysis of historical buildings. The HBIM of the Church of St. Francesco of Rocca Calascio (AQ) was built initially using the metric data produced from the photogrammetric digital survey, respecting the development requirements both in geometries (LOG) and in information (LOI), as well as in reliability (LOR) and in detail (Lod). This parametric model facilitates the documentation and sharing of a mass of data relating to the architectural heritage, and the correct knowledge and enhancement of the same. Furthermore, it allows the management and use of archaeological data, as well as for modelling, in the monitoring and design phases of conservation or fruition interventions, going beyond the boundaries of the disciplinary sector.

Keywords—architectural heritage knowledge, buildings archaeology, archaeological data management, digital photogrammetric survey, HBIM

I. Introduction

Assuming that the documentation of the historical built heritage is a prerequisite for knowledge, conservation and enhancement, the international scientific community has long sought to make use of digital 3D models, taking advantage of the recent possibility of parametric digital modelling for this purpose. Over the last ten years, there has been a growing interest in the HBIM, according to a broader meaning than originally coined in 2009, which was mainly linked to the creation of parametric libraries for historical buildings. The process of gaining knowledge of an historical building involves the study of its characteristics, its history, materials used in its construction as well as its structural aspects, in order to identify the features that need safeguarding. In this perspective, within the scope of the knowledge-gaining process the use of non-destructive diagnostic techniques, like archaeological analysis of the masonries, has been shown to be more effective in responding to these different requirements. The research provided the information necessary for the development of an HBIM aimed at showing how in-depth-knowledge can contribute to the preservation of historic buildings. The parametric model of the Church of St. Francesco of Rocca Calascio (AQ) was created by processing the various Stratigraphic Units of Masonries (SUM) within the building, identified through archaeological analyses. This highlighted the different construction phases of the architectural complex and to topologically connect the information to it.

II. The case-study: the Curch of St. Francesco at Rocca Calascio (AQ)

The case-study chosen to test the integration of a photogrammetric survey, archaeological analysis and parametric model was the church of St. Francesco. This rural church is located in the historical Barony of Carapelle, along the road to Rocca Calascio, the most famous fortified settlement in the area (fig. 1).

Fig. 1 – Images of the Rocca Calascio settlement with the castle, the village and the church studied.

The building was restored in the 1985. It has a single nave, divided in two by a round arch, and covered with cross vaults. Inside the Church the masonry is plastered, but traces of XVI century frescoes in some portions of the walls are visible, unfortunately badly preserved. The church is covered by a lean-to roof and, on the facade, it has a portal of worked local stone, with corbels supporting an architrave and a tympanum with a frescoed semi-circular lunette. The traces of older structures visible near the church can be interpreted as the remains of the medieval settlement, a period in which the church played an important role with its annexed hospital for the poor [1]. The correlation between documentary and material sources, the latter derived from the archaeological analysis of the monument, has permitted the definition of the evolution of this religious settlement, which was conditioned by the historical, economic and social events of the Barony [2].

III. THE KNOWLEDGE PROCESS THROUGH A MULTIDISCIPLINARY APPROACH

The ITC-CNR research team of L'Aquila has for several years adopted a multidisciplinary approach to the study of historical buildings by virtue of the various aspects that characterise this type of cultural heritage. To the structural and mechanical analysis, aimed at assessing seismic risk, which reflects the vocation of the Institute, are also associated: diagnostic investigations for estimating the degradation and conservation of surfaces; stylistic and architectural investigations aimed at interpreting the spaces; and archaeological analysis useful for identifying evolutionary events and reconstructing historical dynamics. The tool mostly used for linking the several disciplines is the three-dimensional survey which today, thanks to the development of hardware and software, is increasingly used to interprete the results of research. In 2017, a photogrammetric survey of the Church of St. Francesco and the nearby ruins was carried out using SfM algorithms with the Agisoft Photoscan software. Afterwards the model was post-processed with the Meshlab software for optimisation through remeshing and merging operations (fig. 2). From the photogrammetric survey, validated geometrically and in its colorimetric data, thanks to photorealistic texture, a bidimensional graphic documentation like high resolution 2D photoplan, was generated, together with plans and sections. These supports, together with the three-dimensional digital model of the church, were used for archaeological investigation, also facilitating remote verification operations and greatly reducing field analysis in terms of time.

Through the application of the stratigraphic method, the different Stratigraphic Units of Masonries (SUM) have been identified; this corresponds to the historical traces of destructive and constructive actions visible on the walls. The archaeological analysis, implementing a critical review aided by the survey, made it possible to group the SUMs into periods of activity and linked to a Matrix (Harris' diagram) aimed at identifying a relative chronology. The masonry was then analysed in detail and classified according to the construction techniques, the materials used and the manufacturing signs; this interpretative process permitted the creation of a chronological-typology and reconstruct the evolutionary dynamics of the church (fig. 3).

Although here the attention is focused on archaeological data and the integration of these into the parametric model, it is important to underline that a diagnostic analysis was conducted to record the state of conservation of the painted surfaces and investigations aimed at assessing the seismic risk [3].

The research results have been reported on digital twins through different test experiments aimed at creating semantic models. These can be used in different ways: from the simple pdf 3D format for data sharing [4], to the use of VR in an immersive environment for an interactive and participatory visit. This mode, structured on a multilevel, allows to manage a considerable amount of data, thanks to the easy switch between different models and formats from the realistic photogrammetric model to the one with the archaeological results [5].

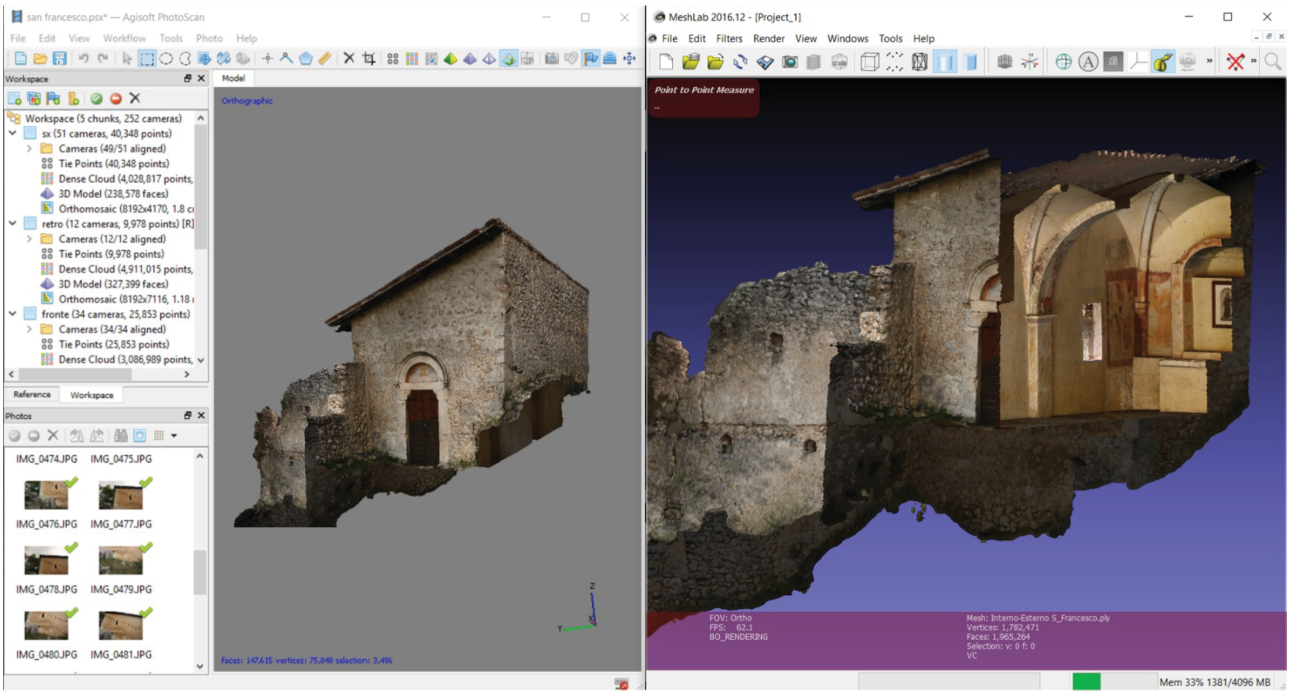

Fig. 2 – Screenshot of the Agisoft Photoscan software used for the photogrammetric survey of the church and screenshot of the Meshlab software used for remeshing process.

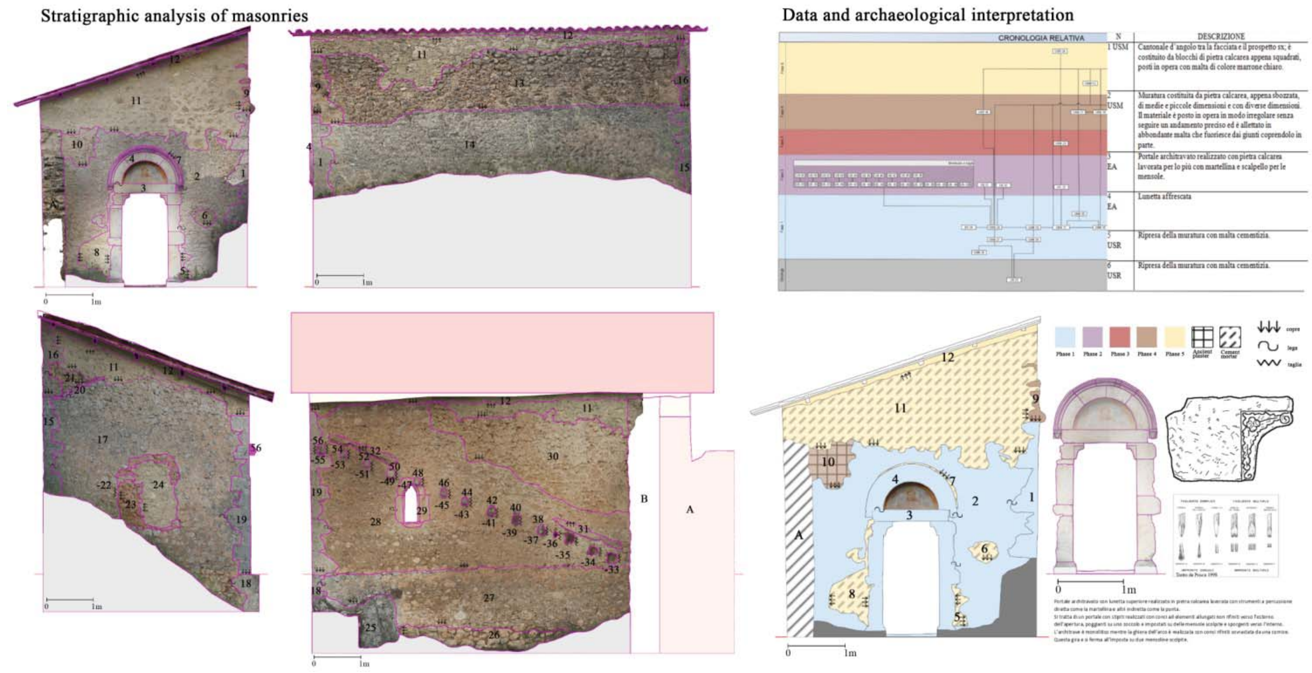

Fig. 3 – Orthomosaic generated by Photoscan software showing the Stratigraphic Masonry Units (SUM) and the archaeological data with the critical relief resulting from the archaeological interpretation.

IV. From the archaeological analysis to the parametric model

The potential of BIM for documentation and knowledge management, but also for the management, conservation and enhancement of the architectural heritage is undisputed. Several research teams have however been wondering for some time about how the procedure can be adapted to the historical construction and, although the methods and methodology for the construction of the models have been defined, the problem is still unsolved [6, 7, 8, 9 10, 11, 12]. Furthermore, automation processes aimed at the construction of parametric objects from point clouds in BIM are still the subject of debate, which is not yet entirely possible [13, 14] as the procedure, with difficulty, adapts to the uniqueness of historical buildings.

More interesting are the tests that aim to apply the potential of parametric software to archaeology, both for excavation [15, 16, 17, 18, 19] and for standing buildings [20, 21, 22, 23, 24, 25, 26].

The experimentation here illustrates, which fully shares the position of the scientific community on the construction methods of the digital twins of historical artefacts, often unique, has provided for the decomposition of the building and its digital reconstruction considering different aspects not only formal, stylistic, architectural functional and historical aspects, but also archaeological data. Starting from the results of the stratigraphic analysis, after a process of critical survey and archaeological interpretation that led to the grouping of the Stratigraphic Units of Masonries (SUM) in periods of activity, we moved on to the three-dimensional modelling of the building, based on the construction phases.

This operating mode has led us to develop a complex model, with a high level of detail, which allows not only the consultation of the historical-archaeological data, but also the consultation of the metrical and geometrical data of the individual units, verifiable and measurable in the model, as well as the stratigraphical relationships.

The modelling of each SUM was carried out starting from the morphology of those identified on the wall surface, adapting slightly the geometries of the originals in order to ensure correct adherence between the neighbouring SUM on the virtual model. In addition, the SUM modelling was verified by testing two different procedures: the first one directly within the Revit software; the second by parameterization in Revit of the several entities modelled with external software on the basis of available surveys, plans, sections and orthomosaics.

In the first procedure, starting from the results of the archaeological analysis, for each type of wall identified, the generic wall present in the Revit library was modified in its characteristics. Each SUM, therefore, was modelled by loading the "wall" entity into the project - chosen on the basis of the typology previous defined - modifying its profiles based on the contours of the SUM with the support of the point cloud and orthomosaics edited by the critical survey. In parallel with the construction of the SUMs, the schedule of the walls was implemented with the addition of the data resulting from the archaeological analysis (fig. 4).

In the second procedure on the other hand, each SUM was modelled with an external modelling software, using the classic solid modelling procedures, always on the basis of the geometries resulting from the two-dimensional restitution of the survey. Each SUM was modelled in a single project using SketchUp software (SketchUp Desktop 2019 rel. February 5th, 2019), respecting the proximity relationships between them. This procedure guaranteed the creation of a metrically validated model without problems of constraints between digital entities. The complete SUM model was later imported into Revit through the FormIt plug-in converting the *.skp file into *.axm format. In this way, each SUM, visible as a "mass", is positioned precisely in the virtual space of the building, preserving its geometric and formal characteristics. The units were then parameterized by transforming them into a "wall" using the "wall by surface" command to transform the mass into a parametric entity. Also in this second case, as in the first one, the different types of walls, created in the Revit project on the basis of the results of the archaeological analysis, were assigned to the SUMs. In parallel to the transformation of the stratigraphic unit into a parametric family, the schedule with archaeological data was implemented (Fig. 5). In addition to the historical-archaeological information, the state of conservation data and the assessment of seismic risk were linked to the individual SUMs, again through the expansion of the schedules. The HBIM built according to the methods described above also represents a useful tool for archaeologists and restorers since it facilitates the analysis and linking of building information to their volume, confirming the potential of the BIM system for the management of archaeological data. Certainly, the construction of a parametric model in this perspective requires considerable effort and for this the two acquisition methods were tested.

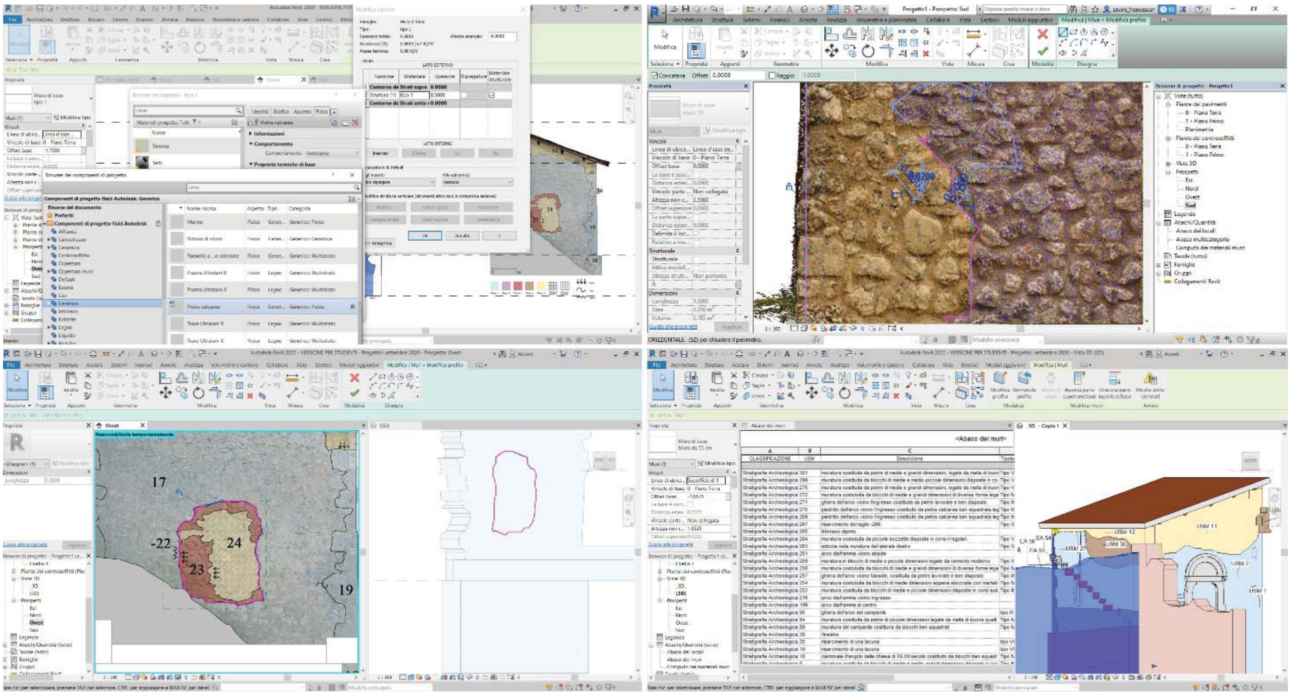

Fig. 4 – Modelling of the Stratigraphic Unity of Masonries (SUM) in the Revit software.

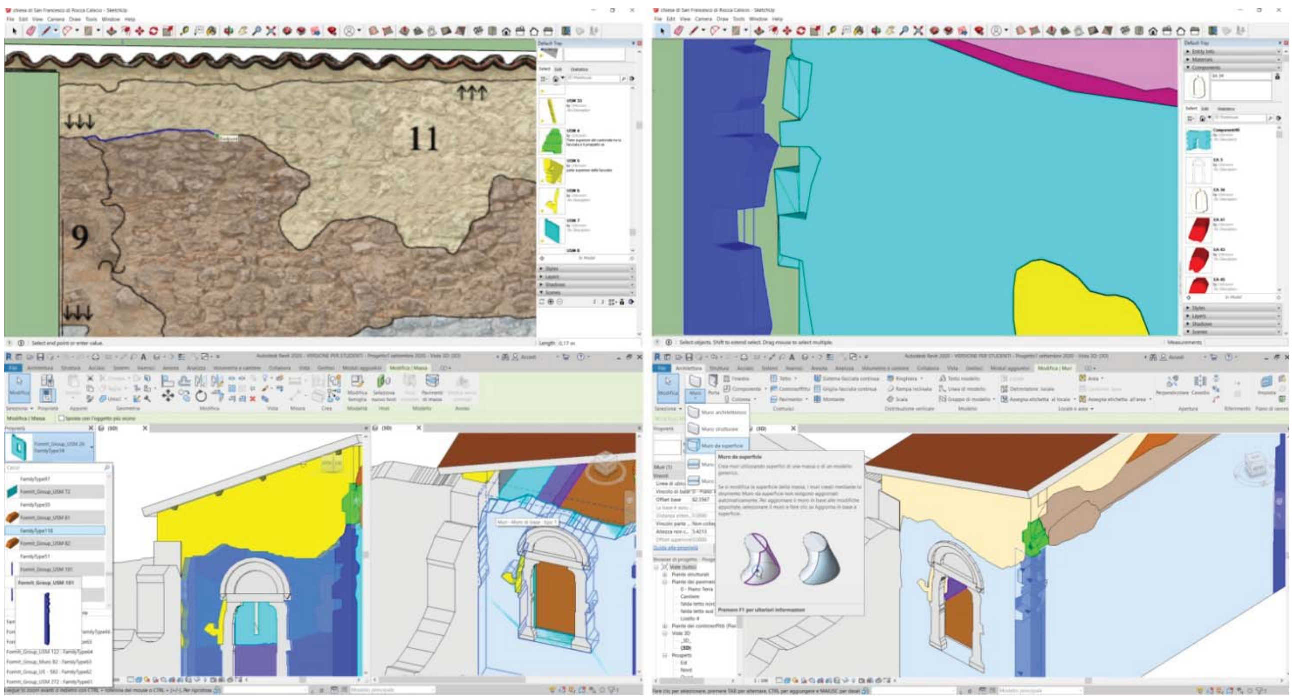

Fig. 5 – Modelling of the Stratigraphic Unity of Masonries (SUM) in the Sketchup software and subsequent import into Revit.

This allowed to reason in terms of realization times and quality of the parametric model itself.

The complexity of modelling individual parts of the masonry, generally irregular, also requires a considerable effort and it is not easy with parametric software tools which, as is well known, still present problems of limited flexibility of usage. On the other hand, the creation of complex architectural elements, such as cantonals, portals, vaults or windows, made with external modelling software, facilitates the digital replication of the artefacts with all components. In addition, importing into the parametric software the architectural elements that characterize the portals and windows is aimed at increasing the existing libraries with special families created on the basis of archaeological data and usable for the creation of digital atlases of the L'Aquila area. The potential of parametric modelling software for the archaeology of the architecture is mainly found in interoperability and in the ability to store, manage and make available for exchange a large amount of heterogeneous and complex data.

Furthermore, the test confirmed the importance of constructing a digital twin that corresponds as closely as possible to the original, respecting both the levels of development and thematic levels. This model, built with the overlapping of different walls, as in real life, becomes a useful tool for analysis aimed at monitoring an asset such as, for example, static and / or mechanical analysis.

V. Conclusions

The work illustrated in this text aims at emphasising the importance of a correct knowledge of historic buildings not only from a structural and mechanical point of view, but also from a historical and archaeological one. For this purpose, it is possible to state that the knowledge process can be increased and enhanced with the application of the methodologies of the buildings archaeology which guarantee the reconstruction of historical evolution and conservation. Through a multidisciplinary approach it is therefore possible to produce reliable digital models also with associated archaeological information.

The team is carrying out in parallel investigations into the archaeology of architecture and experimentation for the creation of parametric families of typical wall types of the territory, with the aim of enriching the libraries starting with the atlases of the historic walls under construction. This will make it possible to increase the use of parametric models of the historic artefacts of L'Aquila by creating a shared database that contributes, in addition to facilitating the creation of the models themselves, to increasing knowledge of the local architectural heritage.

The results presented here, together with those in the validation phase, reinforce the belief that the archaeological analysis of historical buildings can contribute to the delicate and expensive phase of modelling and parameterization of entities, since this approach moves from a critical interpretation, crossing the archaeological data with those relating to the formal and constructive aspects.

These digital twins, strengthened by interoperability between the models, become interpreters of results of a multi-level research that has as its final objectives, not only knowledge management and conservation, but also the enhancement of the architectural and archaeological heritage.

In this context, several ways of using semantic digital models in immersive navigation are being experimented, made with different platforms including Unity 3D, one of the most used Game Engines. These VR navigation systems guarantee, in addition to the visualization of technical analysis and the exchange of data between professionals, a fruition and enhancement of the cultural heritage. In fact, users can visit the church and learn about its history, thanks to an interactive virtual tour that allows access to additional content. The potential of VR is mainly contained in the communication skills typical of digital storytelling, able to translate scientific results into a universal language capable of reaching a wide audience (fig.6).

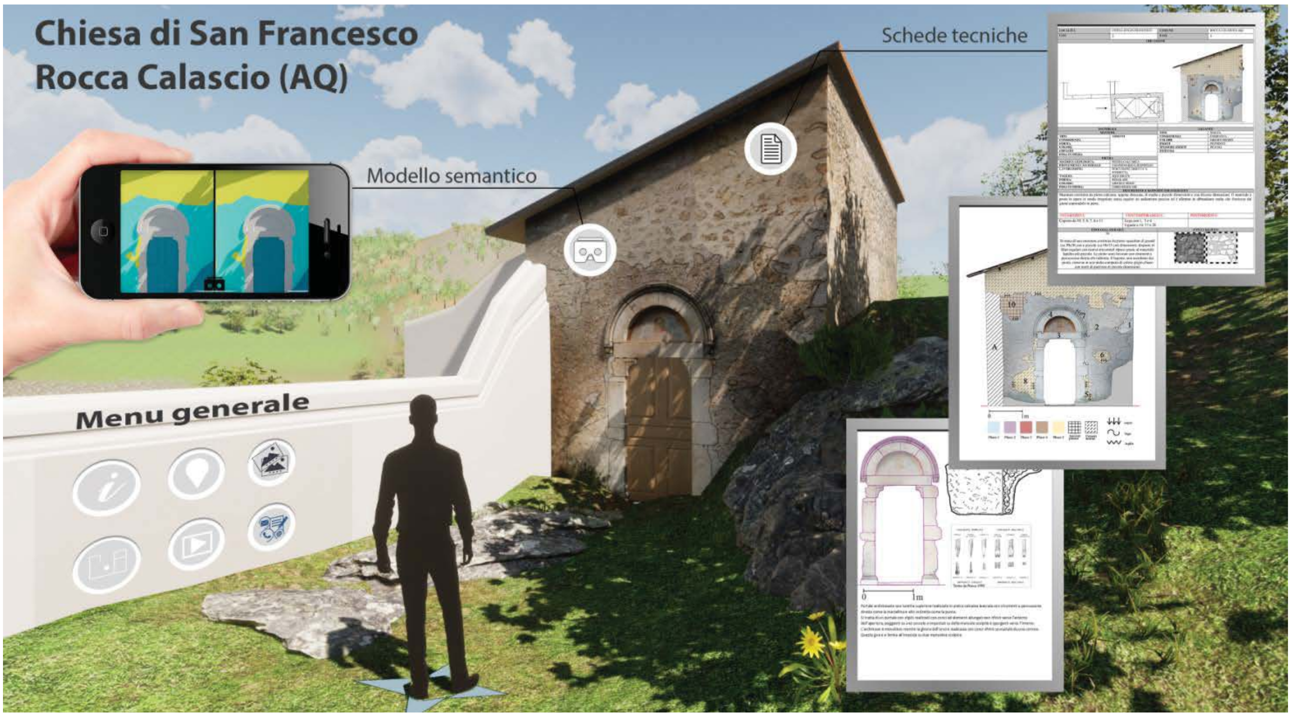

Fig. 6 – Development of VR project for the sharing of archaeological data and enhancement of Cultural Heritage.

CREDITS

Although the contribution was conceived jointly by the authors, Ilaria Trizio wrote paragraphs 1 and 3; Francesca Savini paragraphs 2, 4 and 5.

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