Scans-to BIM for the Cultural Heritage: first results of a study case for a medieval church and its urban context

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Abstract. Raw data, first acquired by several and integrated geomatic procedures and subsequently processed so as to achieve a 3D geometrical model, are the basis for conservation and preventive maintenance of the Cultural Heritage; furthermore, they also allow for the employment of the BIM, Building Information Modeling methodology. By using point clouds elaborated by terrestrial laser scans this research has as main objective the implementation of the BIM technology for the digitalization of the built heritage. In particular a digital three-dimensional model of the medieval S. Maria della Libera Church in Aquino, in the Southern Lazio has been obtained; it represents all the fundamental construction features of the building, the decorative elements and its localization inside a territorial context rich of history and of historical-artistic-archaeological relevance.

1. Objectives

The proposed research has the objective to implement the BIM (Building Information Modeling) technology for the digitalization of the historical heritage and, particularly, for the realization of the three-dimensional digital model of the medieval S. Maria della Libera Church in Aquino (Fig.1). Located along the historical route of the Francigena street that allowed the pilgrims to reach Rome, across the Alps, Aquino is a famous town, where it was born Saint Tommaso of Aquino, theologian and philosopher of the Catholic Church.In this manuscript BIM model, considered as an archive tool of information from several sources, has the aim to experiment, through an illustrative case-study, the possibility to use spatial data surveyed by previous activities, geometric database and characteristics of materials in order to realize a model "ready to use" model. By this we mean a model that, in the future, can represent a basis for safeguard interventions and securing of the historical building, for structural consolidation, conservative restauration, management of maintenance works and, also, for the dissemination of the historical-cultural knowledge on virtual platforms for the musealization and the spreading of the knowledge of the Cultural Heritage [1;2;3].
In this respect it is worth mentioning, as an example, the recent intervention in which terrestrial laser scanning point clouds of the S. Maria della Libera Church have been used as input, for a structural analysis, particularly for modeling masonry vaults and assessing the structural safety. This methodology, called Thrust Network Analysis (TNA), is used for modeling masonry vaults as a discrete network of forces in equilibrium with gravitational loads and exploit concepts and methods of Limit Analysis [4].
Actually, nowadays the Cultural Heritage and tourism sectors try, always more often, to implement innovative digital technologies to provide the enhancement of the historical-architectural heritage.

Hence, the digital model of the S. Maria della Libera Church is configured as a "container model" including a geometric database and information of different content, that represents the connective element among different disciplines and research fields, as required by the BIM technology,

2. State of the art on data and related elaborations about S. Maria della Libera Church

The survey campaign carried out by our research team in other archaeological activities in the ancient Aquinum area has been based on the availability of spatial and geometric database, images, GPS surveys collected not only for the S. Maria della Libera Church, but also for the surrounding archaeological evidences, as the Marcantonio's Roman Arch, extraordinary honorary monument traditionally dated to the 1st century BC, connected in a suggestive way to a corner of the Church, the S. Lorenzo Gate, the ancient Via Latina, surveyed by using different procedures and for multiple study objectives documented in previous papers [5;6;7]. In a future perspective of integrated research and in the PRIN 2015 GAMHer project on the archaeological evidence of ancient *Aquinum,* the ensemble composed of the stretch of the Latina Way, the gate of San Lorenzo, the municipal archaeological museum "Khaled Al Asaad", the church of Santa Maria della Libera and the adjacent arch of Marcantonio, can be framed in an unitary context and connected to Medieval village and to the monumental-natural park of the Vallone di Aquino. This highlights the urge of a plan of restoration and valorization of the heritage, of the historical memory and of the values embedded in them (Fig.2) [6;7].

Figure 1. S. Maria della Libera Church.

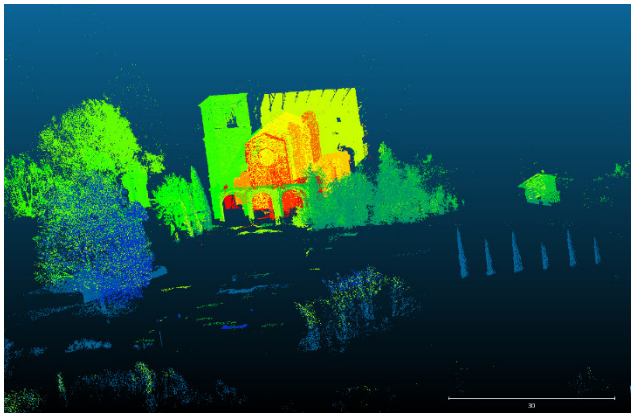

Figure 2. Point Cloud in the area of S. Maria della Libera Church.

With specific reference to the S. Maria della Libera Church, photogrammetric close-range shots and historical-artistic information for some decorative details, mosaics, inscriptions, capitals have been added so that the focus of this work is the use of a Historic Building Information (HBIM) tool that serves as a comprehensive model of the different available databases, guaranteeing their interoperability with a high level of reliability [8;9;10;11]. Specifically databases used for constructing the digital model of the S. Maria della Libera Church are the following ones, as reported in the sequel of the workflow (Fig.3):

- Dense point clouds (Fig. 4) originated from n. 6 Terrestrial Laser-Scanning (TLS) stations and n.9 TLS stations, with accuracy of the order of 0.4351 mm, positioned internally and externally to the S. Maria della Libera Church and its close archaeological evidences. Point clouds have been obtained by using a laser-scanner equipped with a prism that has the function to link the different stations so as to orient the various points clouds without using targets. Point cloud obtained from the alignment of all scans has about 93 million points;
- Dataset GPS points that realize a reference network for surveying around and inside the Church as well as a portion of the ancient Via Latina;

- Photogrammetric images of the principal elements of the sacred building, of the urban context and of finer details.

The use of such diversified data is one of the main strengths of the BIM model.

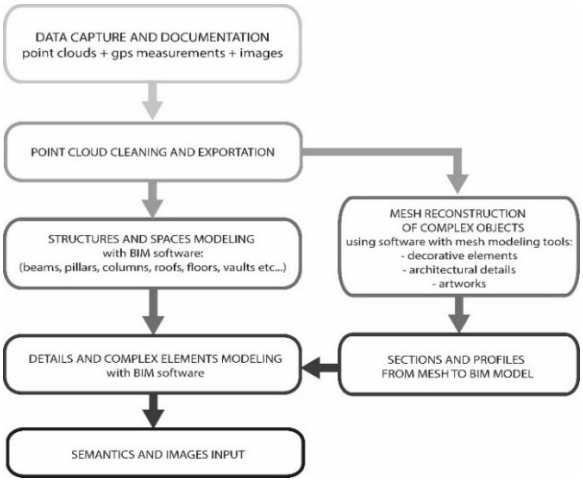

Figure 3. Sequel of the digitalization workflow for the S. Maria della Libera Church

3. Procedures and methodologies

The first step to correctly interpret point clouds is to remove all "disturbing elements", as trees, shrubs, road signs, human figures. Points clouds have been cleaned by using the software Autodesk Recap software (Fig. 5). Fifteen terrestrial laser-scans have been uploaded in .rcs format and the manual elimination of the outliers from point clouds has been carried out. After deleting from the point clouds the anomalous elements that were not object of the survey, the rationalization and preliminary selection operations related to the actual modeling phase have been carried out. Sectioning the point cloud and dividing it into diversified partial areas, it was possible to obtain a separation of the elements and the groupings of useful points for the subsequent modeling phases. In this case the principal selected elements are represented by the S. Maria della Libera Church with the front staircase of access, the main access portal, the buildings adjacent to the Church, the Marcantonio's Roman arch bridge and the remaining surrounding area. These operations are very useful in cases, such as this one, in which the alignment of multiple surveying stations has returned a dense point cloud extended also to the surrounding areas and inclusive of several diversified elements.

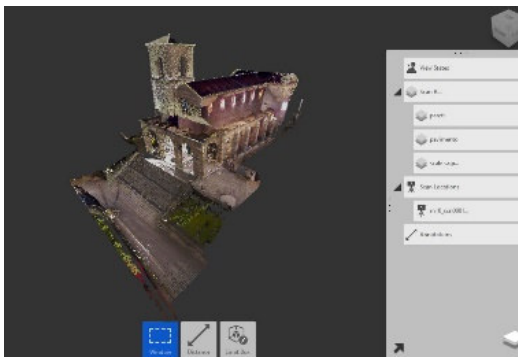

Figure 4. Dense point cloud of the church, portal and staircase in Recap.

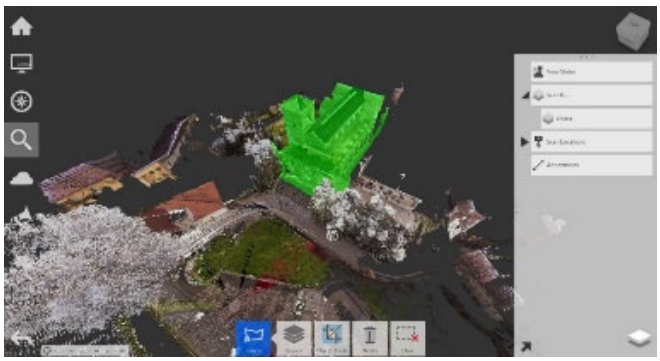

Figure 5. Dense point cloud in Recap and section of the Church.

Subsequently to the clearing and rationalization operations, the point cloud has been exported from the Autodesk Recap for the elaboration of the 3D models.
The second fundamental step as a twofold objective: on one side, it is associated with the insertion of the point cloud inside the software Autodesk Revit, in order to start the geometric modeling of the BIM model suitable to include its main masonry walls, openings, reference elevation levels etc; on the other side, export the point cloud in the MeshLab software (Fig.6). Namely, the point cloud has been exported in format. rcp from the software Recap and inserted in Autodesk Revit; vice-versa the format. pts has been used to export in MeshLab.
Only some parts of the point cloud have been inserted and elaborated in MeshLab, particularly some elements as vaults, capitals, decorative elements in bas-relief, bezels, entablatures of the Church, with the aim to extrapolate models of mesh surfaces.
The elements for which this step has been necessary are those characterized by a significant morphological complexity and/or a reduced dimension. Actually, the mesh surface representing the elements can be inserted within the three-dimensional modeling program Mc Neel Rhinoceros, to obtain the section lines, the profiles and the measurements of the objects necessary for a correct 3D reconstruction and for a dimensional morphological analysis (Fig.7) [12;13].
To mention only a few examples, this procedure has been used in Revit for modeling the cross vaults located in the three spans of the narthex and of the side aisles of the church, the mouldings of the portals and the capitals, etc. The scant capacity of modeling complex surfaces offered by many modeling BIM programs, such as Revit, makes often necessary a further step that exploit NURBS models and/or meshes of 3D reconstructions obtained by means of the Rhinoceros software, or similar ones, that can be later imported inside the BIM models [14]. For small elements the available point cloud wasn't sufficiently dense to correctly detect geometries at the level of planes; consequently, it has been useful the attempt to rebuild models of mesh surfaces from which generate sections and extrapolate more accurate morphological profiles although, unavoidably characterized by a certain level of approximation.

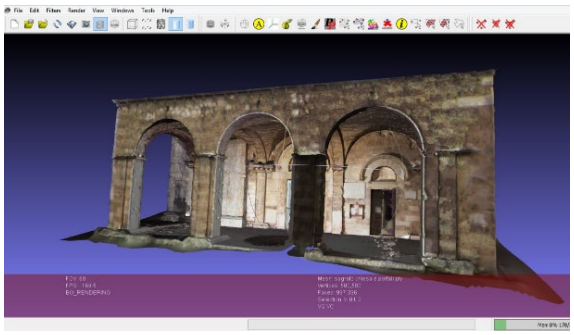

Figure 6. Mesh of the Church portal returned in Meshlab.

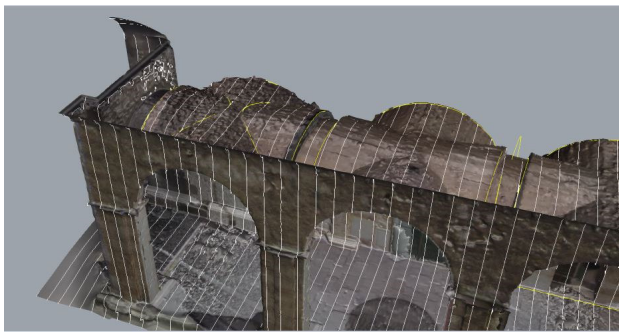

Figure 7. Extrapolation of the sections in McNeel Rhinoceros.

S. Maria della Libera Church is a building which is characterized by the simplicity of the volumes and of the spaces, typical of the architectures in pure Romanesque style (Fig.8). Decorative elements are not present both internally and externally; however some decorative elements of historical-artistic emphasis are present and they have been reproduced and inserted inside the digital model. For example, it is noteworthy, above the main portal of access to the Church, a Byzantine style mosaic that decorates the space included between the architrave of the portal and the round arch that overlooks it.
The accurate structure of the ashlars, the profile of the arch decoration, its support elements and, finally, the mosaic have been digitally rebuilt for representing the portal and its decorative elements (Fig.9).

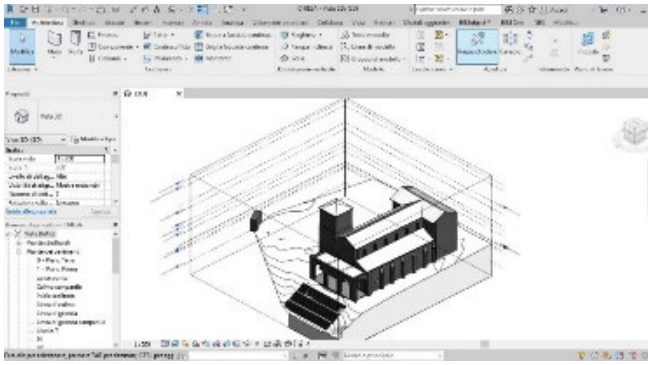

Figure 8. HBIM model of the S. Maria della Libera Church

Figure 9. HBIM model of the mosaic of the main portal.

4. Conclusions

BIM model obtained in the previously illustrated digitalization process is the first result of the re-elaboration of a dataset and information available from previous surveys and documentary collections. The model realized for the S. Maria della Libera Church in Aquino represents the main architectural existing elements and it has an average precision of the order of ± 20 millimeters for the architectural details and decorative elements and ± 10 millimeters for structural elements as walls, vaults etc. The obtained BIM model is appropriate as a preliminary base model for structural checks, for conservative interventions, for historical-artistic investigations. Actually, the authors are continuously improving the quantity and quality of information currently included in the BIM. Furthermore, the model will allow us in the future to develop representations of an immersive informative type in virtual and augmented reality [15;16;17;18;19;20]. Finally, it is worth remembering that the realization of BIM models attests the importance of an increased attention to the aspect of the digitalization aspects of the built heritage, also in situations characterized by limited economic funds, and possibility of re-using available data.

Acknowledgments

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