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Towards the creation of an Open Source HBIM tool for planning diagnostic and restoration activities: the example of the Troia Cathedral rose window.

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***Abstract* – The aim of this work is to set up an HBIM (Heritage Building Information Model) system to facilitate the planning of diagnostic and restoration activities by bringing all archive information into a digital platform, accompanied by three-dimensional models that can be consulted and examined. Frequently, in case of ancient buildings, reconstruct the complete history of the property is not possible, due to a lack of accessible sources. The creation of the HBIM digital tool for consulting the architectural artefact and related information was only the last phase of this work, which began with: (i) Acquisition of archive sources in order to reconstruct the history of the restoration and renovation work on the monument; (ii) Acquisition of information about the diagnostic analyses previously carried out on the monument; (iii) acquisition of data useful for the creation of a digital twin.**

I. Introduction

The analysis of published and unpublished sources preserved in the archives, jointly with all the due investigations on its physical consistency and the information that can be obtained from the diagnostic campaigns, can represent a unique and precious cognitive tool for acquiring the entire corpus of fundamental information about historical architectures, as a basis for a conscious restoration intervention. Frequently, in case of ancient buildings, reconstruct the complete history of the property is not possible, due to a lack of sources and because the existing archival heritage is not known in depth, as it is not completely inventoried, or is kept in various cultural locations (public and private archives, libraries and Superintendencies) that are not always quickly and easily accessible.

Systematising and making all this historical and technical information available for study and consultation in a direct way could be, therefore, a useful tool both for scientific research and cultural dissemination, and for planning/decision-making support in Cultural Heritage sector. The direct access to this body of information will facilitate and qualitatively improve the conservation and enhancement work carried out by technicians.

Rethinking this system by channelling all the data into a single reference tool can therefore allow a complete knowledge and anamnesis of the Heritage, avoiding incurring in incorrect planning choices because the lack an adequate cognitive substratum of the artifact.

All sources of information, in addition to historical and archival data, must be considered in a full-ranging approach aimed at improving the historical-constructive knowledge of the monument: in the field of building heritage conservation, investigation techniques, non-invasive and non-destructive analyses, represent a fundamental means for physical, chemical, constructive and mechanical characterisation.

Making anamnesis and diagnosis an operational protocol and a method to support restoration projects

means playing an active role in generating knowledge on the different components of the building, with the possibility of comparing different methods of investigation to suggest and verify various hypotheses.

In recent years, the development of increasingly high-performance technologies for the creation of (i) digital twins [1]–[3], (ii) virtual reconstruction software [4], (iii) reality capture tools [5]–[7], (iv) 2D and 3D GIS software, and (v) BIM and HBIM [8]–[11] have given an enormous boost to the work of understanding, studying, preserving, and safeguarding architectural cultural heritage.

The aim of this work is to set up an HBIM (Heritage Building Information Model) system to facilitate the planning of diagnostic and restoration activities by bringing all archive information into a digital platform, accompanied by three-dimensional models that can be consulted and examined.

II. Materials and Methods

A. *Case Study*

The Cathedral, main place of worship of the city of Troia (Foggia province), is one of the most valuable examples of Romanesque architecture in Southern Italy [12], [13].

The construction history covers a time frame between the end of the 11thand the second half of the 13th century, from the foundation year (1093) to the construction of the rose window on the upper façade register.

The history of the Cathedral's construction is complex. The plan, a latin cross with three naves, a transept, and a single apse, has been developed in several construction phases on the foundations of a pre-existing church dedicated to Santa Maria (1083-1086).

The primigenial three-naves layout separated by twelve columns on two rows and a 13th column at the side of the first column on the right was enriched by the construction of the left arm of the transept at the end of the 12th century. The project probably included the construction of the right arm, which was not built until the 18th century, during a restoration intervention. The third phase was characterized by the construction of the cross vault of the choir and the apsidal rose window in the presbytery area, while the last constructive phase, dating from the second half of the 13th century, was mainly focused on the construction of the famous rose window on the upper register of the main façade, a superb example of Romanesque art composed of eleven twin-columns, external and internal, mostly made of reused marble.

During the Renaissance period and the 17th century, the construction's history has seen a succession of restoration works required after damage caused by seismic events (1456, 1627, 1731) [14]–[16].

Restoration works were assigned to the architect Travaglini in 1857, as reported by Prot. n. 2677 of 25.05.189 Archive SABAB of Bari. In 1956, the decision to de-restore the Cathedral was made, understanding the monument as a document to be defended against any form of falsification [17]. Thus, the 19th-century cathedral gave way to an austere Apulian Romanesque façade.

The static conditions of some parts of the cathedral, including the rose window, continued to cause concern due to reiterated absence of maintenance: during the twentieth century, the Cathedral has been interested by various restoration and consolidation works, followed by the latest architectural and structural restoration of the façade and of the rose window in 2004 as reported by protocols produced between 1902 and 2002 and deposited at Archive SABAB of Bari [18]–[45] (Fig. 1).

Fig. 1. Photo of the rose window of the cathedral, acquired by drone from N. Abate.

B. *Data acquisition and creation of the digital tool*

The creation of the HBIM digital tool for consulting the architectural artefact and related information was only the last phase of this work, which began with three distinct but fundamental activities: (i) Acquisition of archive sources in order to reconstruct the history of the restoration and renovation work on the monument; (ii) Acquisition of information about the diagnostic analyses previously carried out on the monument (e.g. type of analysis, investigated area, used tools, results); (iii) acquisition of data useful for the creation of a digital twin, metrically correct and georeferenced, on which to operate with the HBIM method.

The anamnesis of previous interventions, as well as of diagnostic activities, in the context of planning restoration and diagnostic activities is fundamental to (i) understand the material evolution of the monument over time (e.g. materials, additions, reconstructions), and (ii) have a dataset of diagnostic data already available on which to work. These operations were mainly bibliographic, archive and library collection activities. This activity was followed by the creation of weighted cards in which, for each element of the monument involved in previous activities, a card was created with connecting elements (keys) to other cards, in order to facilitate searching within a relational database. The creation of the three-dimensional digital model was made, instead, using two distinct techniques: (i) aerial photogrammetry using a DJI Matrice

210 v.2 with a 20MP camera, to obtain the three-dimensional model of the roof and the areas not reachable from the ground [46], [47]; (ii) laser scanner Trimble X-7 inside and outside the Cathedral of Troia [4], [48] (fig. 2).

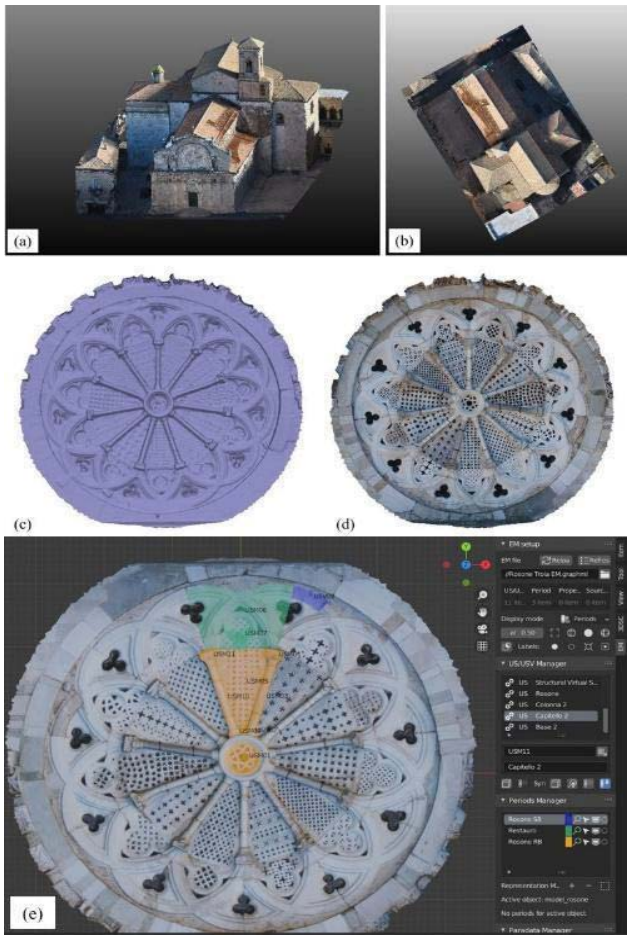

Fig. 2. (a-b) Fusion of the cloud of points obtained by laser scanner and drone; (c-d) Three-dimensional model of the rose window of the cathedral; (e) HBIM preliminary operations.

Once all the data related to the cards and the three-dimensional model were obtained, the open source 3D modelling software Blender was used for the creation of HBIM, with the addition of addons: (i) yEd graph, and (ii) Extendend Matrix palette v.1.2. In this way it was possible to associate the collected information to each single element modeled three-dimensionally and create a network of connection between the various elements (fig. 3).

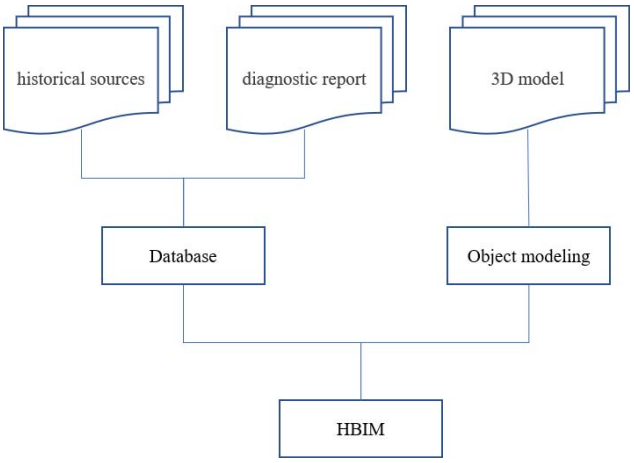

Fig. 3. Flowchart.

III. RESULTS AND CONCLUSIONS

The result of this approach was the creation of an easy tool for questioning the evolution of the monument and the studies carried out on it. In particular, this tool proved to be an easy tool for finding information in a complex monument such as that of the Cathedral of Troia (fig. 4). The speed of information retrieval along all the elements implemented within HBIM makes it extremely easy to approach the planning of new analysis and restoration campaigns, avoiding redundancy of activities (e.g. to repeat analyses already made in precedence for the impossibility to retrieve the data) or the erroneous understanding of the same monument for lack of knowledge (es. wrong interpretation of the zones restored in past).

The HBIM model would, in fact, make it possible to relate a considerable amount of heterogeneous data by means of ID and key elements such as the type of investigation conducted, the architectural element investigated, the construction material, etc.

Each relating table would talk about the different kind of surveys, indicating their type, the methodology of execution, the staff involved and the results obtained (fig. 4).

A digital tool designed in this way provides support for knowledge, analysis and planning of interventions based on the interoperability between the building's history and its actual diagnosis, guaranteeing a twofold result. On the one hand the design of an integrated system which, starting from historical data and data collected in the field, makes it possible to manage and make usable all the information known about the monument, and on the other hand the possibility of implementing and modifying the same information model in real time with new data obtained from experimental surveys, monitoring and interventions in progress.

This is particularly convenient in a complex monument such as that of Troia, since the Troia's Cathedral literally a

palimpsest of practices and techniques a period of time that is unparalleled: from the mid-nineteenth century to the entire twentieth century, up to the early 2000s.

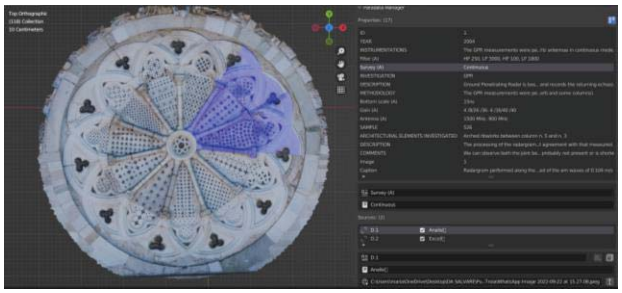

Fig. 4. HBIM model of the rose window of the Cathedral with the associated GPR survey information conducted on the arched ribworks between column n. 5 and column n. 3

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V. ARCHIVAL FUNDS

Archive SABAB (*) of Bari. Position: FG LVIII

Folder n. 1 (1892-1950): [18] Annex n. 4 of

09.03.1902; [19] Article of 11.09.1906; [20] Annex n. 2 of 17.11.1910; [21] Prot. n. 1388 of 04.08.1927; [22] Expertise of 16.11.1928; [23] Prot. n. 1738 of 20.08.1948; [24] Estimate of 16.11.1928; [25] Report of 17.02.1937; [26] Prot. n. 1854 of 17.03.1938; [27] Prot. n. 1232 of 13.09.1946; [28] Expertise of 15.06.1948; [29] Expertise of 16.09.1958; [30] Expertise n. 33 of 14.05.1958.

Folder n. 2 (1950-2000): [31] Prot. n. 5017 of 03.12.1965; [32] Dossier of 06.07.1968; [33] Prot. n. 7976 of 14.07.1975; [34] Prot. n. 5066 of 19.06.1978; [35] Prot. n. 3066 of 09.02.1988; [36] Prot. n. 2603/MF of 12.02.1988; [37] Prot. n. 7502 of 21.05.1991; [38] Prot. n. 020202 of 28.08.1997.

Folder n. 3 (2001-2002): [39] Prot. n. 010521 of 12.04.2002.

Folder n. 4 (2003-2008): [40] Prot. n. 6667 of 18.07.2003; [41] Prot. n. 8985 of 30.09.2005; [42] Prot. n. 08971 of 18.10.2005; [43] Testing of 26.07.2007; [44] Prot. n. 0011387 of 27.11.2007; [45] Prot. n. 6667 of 14.03.2003.

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