Protocols of Knowledge for the Restoration: Documents, Geomatics, Diagnostic. The Case of the Beata Vergine Assunta Basilic in Guasila (Sardinia)

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Abstract. For several decades, the conservation and maintenance of the historical architectural heritage in Italy have become one of the central problems within the scientific community of architects, restorers, and engineers. In fact, historic buildings represent not only an important symbol of the country's culture but also a significant economic resource linked to tourist flows. Unfortunately, many historic buildings are in a state of neglection or in a dangerous state of conservation. It is therefore important to activate a series of actions to preserve and conserve this built heritage. In this context, a transdisciplinary approach that includes an accurate historical, dimensional, and material knowledge has fundamental importance to allow a correct design for restoration actions and the possible reuse as well as to allow this heritage to be usable and active. This article presents this integrate approach carried out for the specific case of the Basilica of the Beata Vergine Assunta in Guasila (Sardinia) with a particular focus on the results obtained from historical-documentary investigations, geomatics and petrographic surveys. These studies have been a fundamental base of knowledge for the last interventions of safety and extraordinary maintenance of the monument implemented in 2019.

Keywords: Geomatics · Diagnostics · Transdisciplinarity · Conservation · Cultural heritage

1 Introduction

In the last decades, the conservation and maintenance of the historical architectural heritage in Italy have become one of the central problems within the scientific community of architects, restorers, and engineers. In fact, historic buildings represent not only an important symbol of the country's culture but also a significant economic resource linked to tourist flows. Of this vast Italian historical built heritage only 33% is declared to be of cultural interest and therefore subject to direct constraint by the Italian Ministry of

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Culture [1]. The rest, for reasons of different nature but mainly for economic issues, very often lies in a state of neglection or in a precarious state of conservation. Numerous management initiatives have been planned for this huge heritage at risk, including the establishment of the Risk Card Territorial Information System, developed by the Higher Institute for Conservation (formerly ICR) [2] and focused on the concept of vulnerability for the assessment of the conservation status of the heritage. Another example is the "red lists" of Italia Nostra [3], which collect the sites to be defended on a regional basis. These are tools still in a phase of implementation where a clear numerical data is not yet assumed. What is clear is that more than half of the existing heritage would require maintenance actions to avoid getting into the current precarious state of conservation and requiring restoration.

These aspects make important to activate actions to protect this heritage, especially against the destructive events related to climate and territorial changes such as earthquakes, floods, pollutions as well as weathering linked to the historical passage of time.

If from an economic point of view, the scarcity of facilitations for interventions does not encourage their continuous maintenance, on the other hand, it is also true that restoration projects very often follow one another, without an in-depth knowledge bases and therefore not understanding the real causes of deterioration. As it is well-known, in order to carry out all the conservation actions, the understanding of the state of conservation of buildings has paramount importance. In fact, only with this information the conservation project can be really activated, giving new life to heritage.

Therefore, the trans-disciplinary approach, which offers the study and synergic involvement of different figures such as that of architectural historians for the analysis of the documentary and photographic archives of the major protection bodies, such as Superintendencies and private parish archives, geomatics for the survey aimed at geometric and dimensional knowledge and, finally, petrographers for the material analysis and the assessment of the material state of conservation, is certainly the most effective protocol for reaching this in-depth knowledge [4–8].

This paper presents this approach declining for the specific case of the Basilica of the Beata Vergine Assunta in Guasila (Sardinia) and the results obtained, fundamental bases knowledge for the last intervention of safety and extraordinary maintenance of the monument implemented in 2019. This late nineteenth-century basilica showed signs of dangerous infiltration of rainwater both on the dome and on the plaster with alarming detachments, the walls showed dangerous cracks and signs of humidity deserving of careful investigations. The bell tower, attacked by vegetation that has settled in the cracks, threatens devastating collapses, and requires safety measures. Thanks to the results of this in-depth and integrated study it has been possible to set the bases of knowledge, the current state of conservation of the fabric and the causes of its structural problems, suggesting to architects and restorers balanced guidelines for the intervention of restoration, especially to optimize timing, money, and the usability of this monument.

2 The Transdisciplinary Protocol for the Restoration

Every restoration project needs to be based on a transdisciplinary knowledge protocol to be effective and long-term. This is intended "not only as the integration of knowledge of a specific research topic but also as the assimilation of reciprocal bodies of knowledge, overcoming the concepts of multidisciplinary and interdisciplinary works [9]. In such an approach, there are no boundaries between sectorial disciplines that are fully integrated with the aim of a deep knowledge of the monument in every aspect: from the historical-archival point of view to the geometric-architectural and material-structural features, as well as to those related to pathologies of decay and their causes, crucial information regarding the state of conservation. Then, it is possible to hypothesize the possible interventions to be performed.

This approach considers the integrated use of different techniques and different skills that, according to the current standards of good practice of conservation and preservation of the architectural heritage such as the ISO 13822:2010 "Bases for design of structures-Assessment of existing structures", should involve the use of non-destructive methodologies and tools [10, 11] designed to ensure the geometric surveys, detailed inspections, material testing and structural analyses [12–14].

In particular, the transdisciplinary protocol for the knowledge of the cultural heritage carried out, consists by the integration of three fields of research:

a) architectural history with the analyses of documents and iconographic materials, useful to reconstruct the unknow construction history of the fabric and its evolution considering its context and the previous restoration works. In this phase all information can be indirectly investigated through the consultation of all the documents regarding the monument: bibliographic, archival, cartographic, iconographic, and archaeological studies have paramount importance for reconstructing the building's history and evolution, providing important information about the building materials and techniques as well as possible previous interventions. Also, prior geometrical surveys, when available, can help in this phase of knowledge. This phase of analysis should be conducted through the consultation of National, Civil, Ecclesiastic and Council Archives, the documentary, photographic, iconographic archives of the Superintendence for Architectural, Landscape, Historic, Artistic and Ethno-Anthropologic Heritage and the Archaeological Superintendence.
b) geomatics surveys, fundamental basis for the geometric knowledge and health assessment of a building. During the last decade, the Terrestrial Laser Scanner (TLS) has been one of the main methods for the 3D survey and modelling of historical and cultural heritage, providing high data acquisition rates and high spatial data density [15–17]. Interesting reports on point clouds from TLS to 3D reconstruction can be found in Napolitano, 2019 and in Remondino, 2011 [18, 19]. Many works with the TLS have also involved the survey of paintings or frescoes to obtain orthophotos to be used for the construction of virtual paths [20]. On the other hand, there are countless works for the study of deformations or for the conservation of the architectural heritage [21, 22]. Currently another geomatics technique, widely used to produce high-density point clouds is the multi-image Close Range Photogrammetry (CRP) which is based on the Structure from Motion (SfM) algorithm [23, 24]. CRP

produces dense point clouds with high accuracy [25] that can be treated like those from TLS. The state-of-the-art of dense image-matching is discussed in Remondino, 2014 [26], where a comparison of the available software is also presented. Most of the published studies [27–29] estimate the accuracy of the point cloud using targets or through sections extracted from the point cloud and compared with the design ones or to preservation of archaeology and cultural heritage based on point cloud surveys. In Remondino, 2012 [30] a critical review of the developments in automated image processing is discussed. In architectural surveying it is common to find complex geometries with different configurations, the combination of the two TLS and CRP methods must therefore be seen as an integration that can provide a more complete 3D model than the use of individual techniques [31]. The main advantage of this technique is surely its ability to accurately acquire the colour of the surveyed object. This is a substantial difference with the TLS technique, due to the nature of the data acquisition method [32, 33] for this reason, the two techniques are often used together.

c) material analyses, investigated through a detailed diagnostic protocol with minero-petrographic analyses such as optical microscope and Xray-diffraction. Materials represent topography and the interaction between nature and builders' skills and abilities. Not only stones but also mortars, mixtures of aggregates and binder are investigated because an integral part of historical masonry with the functional role of bonding or protecting. In this light, this step of the protocol underlines the importance of the characterisation, the identification of historical mortars and the analysis of their state of conservation considering composition, shape, size, particle size of aggregates, binder type, and to the assessment of the level of degradation. This analysis allows to define the nature of the natural materials, to hypothesize the origin and the extractive sites, and to identify the different types of decay [34].

3 Results

The codified methodology has been carried out for the study of the Beata Vergine Assunta Basilic placed in Guasila (CA), a neoclassic monument designed by the local famous architect Gaetano Cima in the middle nineteenth century (Fig. 1). Since its construction, this monument has shown signs of decay and structural failure such as cracks and infiltration of rainy water mainly located on the dome, on all the smaller vaults, arches, and headers. All these problems concerning the quality of the building materials, a local sandstone historically quarried in the surroundings hills, and the poor building skills have been investigated to understand the origin of the current state of decay and to define, after several years of unsuccessful restorations works, effective guidelines for the safeguard of the monument.

In the following paragraphs results arisen from the application of the protocol are presented, with specific regard to historical, geomatics and diagnostic investigations carried out on the Basilica in wider research titled *Architectural and structural survey of the Santuario della B.V. Assunta in Guasila,* financed by the Guasila council [35].

Fig. 1. Aerial view of the Basilic (Pilia E.)

3.1 From the Document to the Monument

The study of the documents has been essential to reveal the controversial construction history of the basilica, built on the ruins of a previous church and as already known, characterised by several building issues related to the poor quality of craftsmanship and materials used. Three archives concerning documents, photographs and iconographies were consulted in order to reconstruct the historical events related to monument: the first one is the Parish archive, which provided important information about the foundation phase of the church with drawings and written documents (reports of project, sketches and correspondence about the construction site) that state detailed design intentions of the architect Gaetano Cima, the ongoing planned changes, problems and outcomes of the construction site; the archive of the Superintendence of Architecture, Landscape, Historical, Artistic and Ethno-anthropological Heritage of the Provinces of Cagliari and Oristano and of the Guasila municipality which instead provided projects, drawings and photographic evidence of the restorations carried out on the monument, interventions that start as early as 1897, after only forty years since the consecration and opening to the community happened.

Thus, the data contained has been for the first time crossed with the aim of reconstructing not only the chronology and the overall stratigraphy of the monument, in some phases still unknown, but also to identify materials and construction techniques used in the construction and restorations phases, going to understand the possible causes of decay in place. All the materials have been then cross-checked with the direct analysis of the monument, finding interesting and crucial findings and differences for planning the last intervention of restoration.

The Parish Church of the Beata Vergine Assunta was built in 1839 by Gaetano Cima [36]. The construction site started in 1842 is immediately linked to controversy with the impresario Crobu who realised several variations during the execution phase of the building site. It is so clear that the main structures and the decorative apparatus are therefore different from the original project placed in the Parish archive.

It is precisely because of these faults during the construction that it is already necessary to require a first restoration in 1897, when Vivanet, Director of the Regional Office of Antiquities and Fine Arts receives the first report concerning the presence of injuries and recommends the use of concret instead of ordinary mortar, for "profiling of the lesions". From this first intervention of restoration, highly incompatible with the materials of the structure, several ineffective interventions were designed and conducted, all aimed at solving two issues that are recurring with continuity during time: the lesions on the elevation structures and the infiltrations of water from the roofs.

As reported in the archives of the Superintendence, the interventions included: the consolidation of masonries with the application of iron chains, the compensation of injuries with iron bars and grout and the mending of damaged masonry (arch. Crudeli, 1954); the construction of a new reinforced concrete retaining wall (1988), operations of "*cuci e scuci*" and armed seams with iron bars (199–1993), the waterproofing of the dome as well as the complete demolition of all the decorated plaster of the dome and its reconstruction (Arch. Rollo, Ing. Medda and Mameli, 1978), the waterproofing and the complete replacement of the roof covering and finally, interventions on the rainwater disposal system and on the fixtures of the lantern to promote the air circulation in the dome (Arch. Secci and Morand, half 80s) [37].

Despite this long series of interventions, we are still facing the same problems of decay: the presence of moisture and water infiltration from the roofs, and widespread injuries on the dome and arches.

Overall, during these restoration activities, prolonged for over a century, it has been possible to recognise the total incompatibility of materials used and the interventions, often not connected to each other creating significant further discontinuities on the masonries. The indirect study of the monument has therefore, accurately outlined the historical facts concerning the monument, providing important information to re-read the factory thanks to the support and integration of direct analysis, focused on studying with reliability the geometries and anomalies already witnessed at the design level and modified over time due to subsidence and diagnostic analysis of characterisation of materials (natural and artificial), considering the specific properties of building and restoration materials, their compatibility and their current state of conservation (Fig. 2).

Fig. 2. Drawing of the main façade of the church. Cima's project is conserved in the Archive of the church.

3.2 Geomatics Survey

The Terrestrial Laser Scanner (TLS) and Close Range Photogrammetry (CRP) techniques were used and integrated for the metric-dimensional survey and 3D modeling of the Basilica. In particular, the entire internal and external building was detected with the TLS. The CRP was used for the internal 3D survey of the dome. The need for this integration was to improve the texture of the 3D survey of the dome and its paintings, a result that could not be achieved with the TLS survey alone, both due to the distance of the TLS from the dome and due to the resolution of the digital camera associated with the laser scanner used.

3.3 Terrestrial Laser Scanner

For the TLS technique, the Faro Focus 3D Terrestrial Laser Scanner was used. It is a compact scanner characterized by an operative range that varies between 0.6 and 120 m, with a ranging error of ±2 mm for scanner–object distances between 10 and 25 m. The scans were processed using the JRC Reconstructor software v. 3.1.0 by Gexcel Ltd.

For the design of the scans, we started by thinking about the geometry of the building and the scale of restitution. The presence of architectural details and the situation of the deformations to be detected were taken into account. From these considerations, it was decided to perform the scans at a resolution of ¼, with 3x quality, which corresponds to a resolution of 7 mm/10 m. To ensure an overlap between the scans of at least 30%, 33 internal scans from the ground and 8 internal scans from the elevator basket were performed to survey some niches not directly accessible by the detector. The external scans were 15 from the ground and 8 from a crane equipped with a telescopic arm on which the TLS was mounted (Figs. 3 and 4).

Fig. 3. TLS survey of the roof

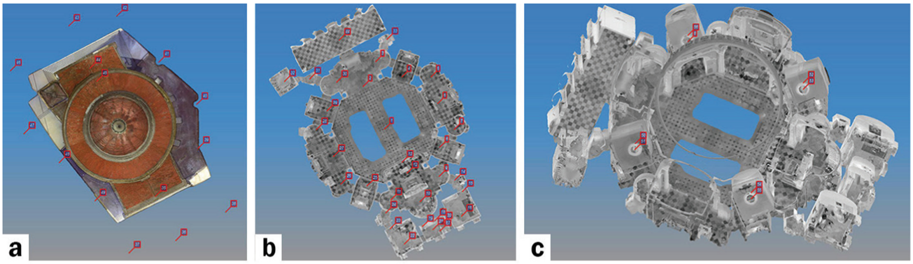

Fig. 4. a) Outdoor TLS stations; b) Indoor TLS stations, ground floor; c) Indoor TLS stations of chapels.

The survey was carried out on 12 October 2017, a non-windy day, and with the crane engine turned off to avoid harmful vibrations that could have affected the scans The 64 scans were initially pre-processed and subsequently, using only natural features, they were pre-aligned and then aligned obtaining closure errors of less than one centimetre. The complete point cloud of the Basilica was therefore geo-referenced in the ETRF2000 reference system (with geoidal heights), through the use of 20 Ground Control Points located outside the Church (Fig. 5) and surveyed with a GNSS survey in RTK mode, using the differential corrections from the SARNET network of permanent stations in Sardinia [http://www.geodesia.biz/sarnet/].

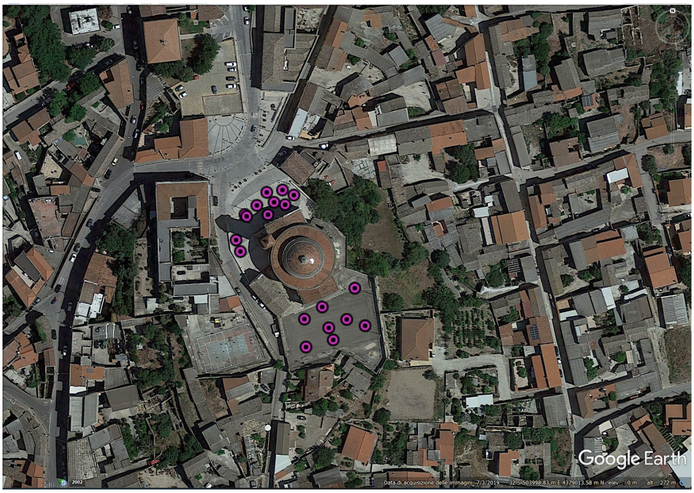

Fig. 5. GCPs position (image from Google Earth)

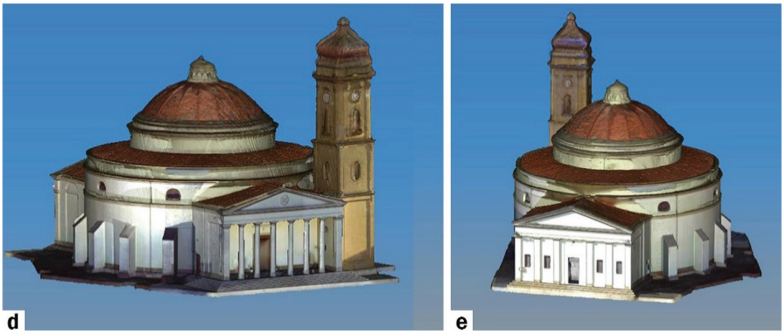

Fig. 6. Front (d) and rear (e) 3D model

After processing the 64 point clouds and obtaining a single point cloud, still using JRC 3D Reconstructor, we produced the mesh and then the 3D model. From this we extracted the following graphic elements:

- horizontal sections at different heights: ground level, ground + 3 m, ground + 6 m (Fig. 7);
- vertical sections;
- orthophotographs of the vertical and horizontal elements, both on the inside and outside, with ground sampling distance (GSD) of 2 cm.

From the sections and orthophotos, through a long editing work, all the drawings of the Basilica's plans, sections and elevations have been prepared (Fig. 6).

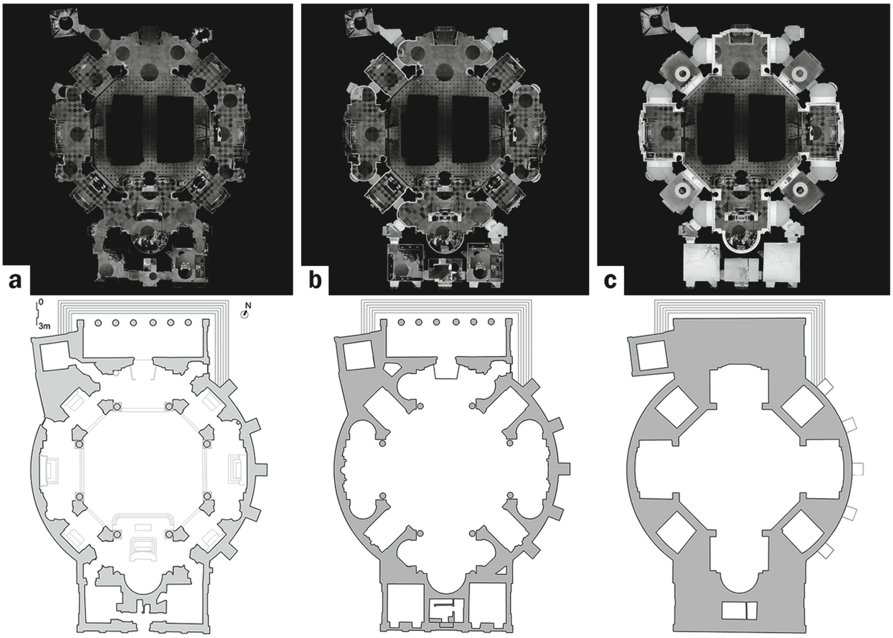

Fig. 7. Orthophotographs and horizontal sections at different heights: a) ground level, b) ground + 3 m, c) ground + 6 m (edited by Pilia, E)

3.4 CRP Survey

The CRP survey was used exclusively to survey the dome of the basilica and thus allow to obtain a high-resolution 3D relief with a high definition of the paintings shown on it (texture).

We used a digital non-metric camera (Canon EOS M3) with a CMOS 22.3 × 14.9 mm (3.7 mm pixel dimension) sensor, Field of View (FoV) 81.5 g, and 24.2 Megapixel resolution; objective EF-S 18–55 mm; the output data formats are Exif 2.3 (JPEG) and RAW (CR2 Canon original).

In order to obtain high metric and texture resolutions, the photogrammetric survey was performed using an elevated platform, with distances between the camera position and the dome varying between 3 and 8 m.

The images were processed with Metashape, a commercial software by Agisoft, using the "Structure from Motion" algorithm. 97 photos have been acquired by the EOS M3 and processed on an HP Z420 workstation with 64 GB RAM, Intel Xeon E5-16200 3.60 GHz CPU, and NVIDIA Quadro K2000 video card.

The image processing workflow follows the standard steps of SfM software with the solution of the Bundle Adjustment on sparse point cloud, external orientation of the block and generation of the dense point cloud. All images have been elaborated in Medium mode, in fact, as verified in Grillo, 2019 [38] the accuracy does not vary with respect to UltraHigh mode and processing times are reduced. The processing produced a point cloud of 11,315,919 points with a processing time of 6 h. The cloud was georeferenced using 10 GCPs extracted from the TLS point cloud. The global RMS of georeferencing is 2 cm. Figure 9 shows the textured point cloud of the dome.

Fig. 8. Internal view of the dome.

Fig. 9. Dome 3D model

3.5 Diagnostic for Materials

The analysis of the materials consisted of the systematic study of natural and artificial materials both used during the construction and the restorations. All these materials studied have allowed us to define the nature of materials, to hypothesize their origin and the quarry of extraction.

Particular attention has been given to the characterization of mortars and plasters in order to define their minero-petrographic nature: composition, shape, size, aggregates grain size, type of binder and to assess their state of conservation. Therefore, a reasoned sampling was carried out on mortars and plasters with scalpel and micro chisels for more compact materials, in accordance with the "Normal Recommendation UNI EN 16085:2012 Conservation of Cultural property - Methodology for sampling from materials of cultural property - General rules ICS: [97.195]".

The number of samples collected, sufficient to represent all the different types of materials, is the result of a preliminary analytical survey conducted in different parts of the structure with the help of a crane during the endoscopic survey campaign. So, different types of mortars, plasters and paint layers made with different techniques at different times have been sampled. These samples were characterised by investigations carried out under transmitted microscopy light. All the investigations were carried out at the laboratories of the DICAAR of LabMast (Mediterranean Laboratory for Materials and Historical-Traditional Architectures). The basilica is located in a landscape that presents a flat and hilly morphology called Trexenta, specifically characterized by silky marl, alternating with arenaceous levels from medium coarse to fine with strong vulcanoclastic component", and anthropic deposits, Eluvio-colluvial and terraced alluvial cultivars. Nine samples taken during endoscopic investigations were characterised by optical microscopy in transmitted light. From the macroscopic analysis of the Church, it was clear that all the load-bearing structures were made of local sandstone as also confirmed by the results provided by the geotechnical surveys. The building material are those extracted in the nearby historic quarries around the mining poles of Nuraminis-Samatzai, Pimentel and reused materials from the previous church and other monuments in the area, The sands, instead, as prescribed by Cima (ACCA, Carte Cima, b.2 fasc. 84) came from the cava de is Concas located in the same municipality of Guasila and now closed.

In summary, the analysis of the material samples shows that these are elements attributable to restoration work (C 02, C 04a-b, C 05, C07 | C 04, C 02). Hypothetically, historical mortars show a finer aggregate and a lower aggregate/binder ratio (C 04b, C 05, C 01). The forms of decay such as the strong decohesion, the presence of biological patinas, as in sample C03, are attributable to the strong presence of water infiltrations from the walls and roofs (Figs. 10 and 11).

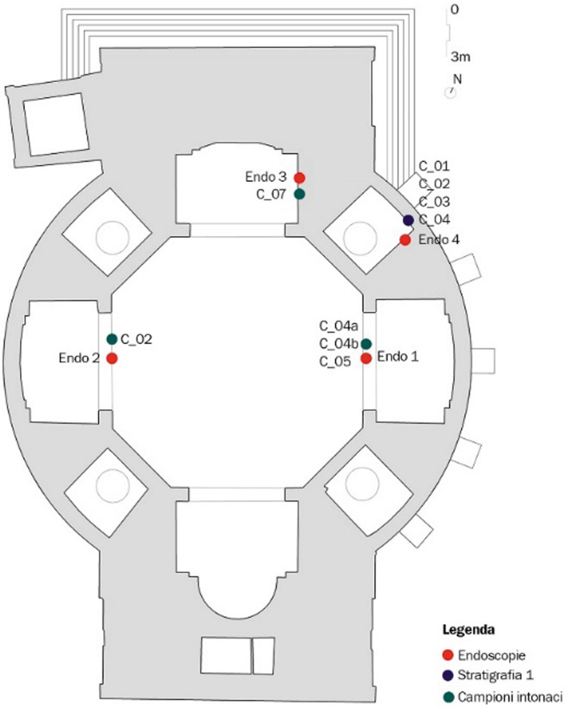

Fig. 10. Map of the samples at the level + 6 m (Pilia E.)

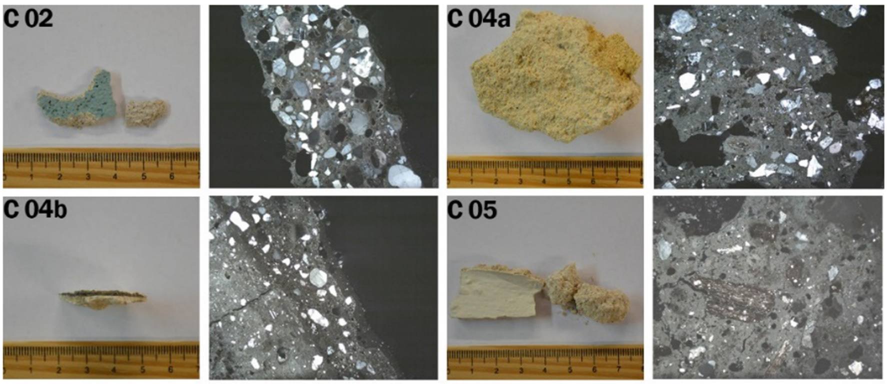

Fig. 11. Minero-petrographic analysis. From the left: macro photo and thin sections under the optical microscope in Transmitted Light (Laboratory analysis: Grillo S.M., LabMaST. Graphic elab.: Pilia E.).

4 Discussion and Conclusions

The research, conducted according to an integrated approach of the investigative field of research, has allowed to outline the history of the case study from the connexion between direct and indirect sources, to define its state of conservation with regard to geometries, techniques and materials, to provide a valid knowledge base for future insights, studies and for the preparation of a restoration project truly suited to the needs of the monument. From the sources we learn the information relating to the reconstruction of the schedule from its origins to today, which we know to be different from the one designed by Cima also from the feedback in the graphic rendering of the geometries of the asset. These geometries highlight a stable structure from a structural point of view, albeit characterized by the presence of widespread lesions present above all in correspondence of arches and vaults, attributable to the typical collapse of the platbands and their consolidation passed with cementitious binder mortars, and other superficial lesions, mainly due to the material degradation caused above all by the continuous infiltration of rainwater. As for the materials, on the other hand, a widespread use of concrete as a restoration material was found, which, being totally incompatible with the factory, has led to further problems of detachment of plaster and loss of decorative apparatus, which can be compensated by means of the constitution of a compatible mortar similar to the historical ones analysed.

Finally, no less important from this cross study is the possibility of having put up for tender the last intervention of 2019 for "safety and extraordinary maintenance of the Sanctuary of the Beata Vergine Assunta" concerning the problems that were still present in the monument such as the arrangement of the lantern, the rehabilitation of the recessed downspouts, the rehabilitation of the mezzanine walls from humidity, the reconstruction of the roof covering on the connection with the bell tower, appropriate natural and mechanical ventilation systems against condensation humidity.

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