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D-SITE

Drones - Systems of Information on Cultural Heritage for a spatial and social investigation

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SIFET Società Italiana di Fotogrammetria E Topografia

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ABSTRACT

The present paper describes the first results of a research project aimed at the metric-morphological and archaeological study of the Church of San Silvestro in L'Aquila.
The workflow has been set up on a preliminary digital survey of the multi-layered structure conducted using integrated acquisition methodologies and techniques, TLS and UAV, which have allowed both to develop a reliable metric basis for archaeological investigations, but also to highlight their potential use in the field of documentation of architectural complexes located in seismic areas for preservation and monitoring.

The Church of San Silvestro in L'Aquila. An integrated approach through TLS and UAV technologies for the architectural and archaeological documentation

1. Introduction

The study is part of a wider research project aimed at providing valuable data for a better understanding of the dynamics of construction and settlement of the city of L'Aquila, from its origins to its current conformation, through the analysis and study of the building fabric of its historic center.

In particular, sites of great importance have been analyzed, which have allowed us to give back helpful information on the building patterns present in the city center and the transformations of building techniques following the numerous seismic activities that have affected the territory.

The project has foreseen the realization of detailed and punctual surveys of the internal and external morpho-constructive characteristics of various architectural complexes, carried out through laser scanner instrumentation and aerial and terrestrial photogrammetry, to evaluate possible vulnerabilities or specific features and, at the same time, to carry out stratigraphic readings of the wall faces, compared to the historical-constructive analyses that emerged during the field investigations.

The analysis has provided a level of detail based on a macro-reading of the city fabric, mainly based on the reconnaissance and macro-stratigraphic analysis by sample of several buildings since the data obtained from a single structure would have inevitably led to misinterpretation of the final data overestimating or underestimating the effects attributable to each earthquake. Moreover, it was decided to initially analyze the vestments of the best-preserved ecclesiastical buildings from a stratigraphic point of view, without restoration, plastering or reconstruction so invasive as to erase the stratigraphy, through a well-established study methodology (Arrighetti 2015; Brogiolo, Cagnana 2012).

Therefore, the proposed work explores the case study of the church of S. Silvestro in L'Aquila, exemplifying and presenting the methodology of analysis and research conducted on a larger scale on the overall historical buildings of the city.

Figure 1. Aerial view of the religious complex of the Church of San Silvestro in L'Aquila.

2. The Church of San Silvestro in L'Aquila

The church of San Silvestro is located in the quarter of Santa Maria, which in 1265 became the property of the inhabitants of Collebrincioni through a royal decree of Charles I of Anjou (Signorini 1868; Equizi 1957).

Many researchers agree in attributing the construction of the building to a date after the earthquake of 1349, based on the studies of Signorini (Signorini 1868, p. 269 ff.). However, other sources testify a San Silvestro already in 1265 or 1285 (Equizi 1957, p. 114), anticipating the building site by almost a century. The first mention of an abbot of San Silvestro dates back to 1323, an element that highlights the potential role of collegiate assumed by the church (Signorini 1868). In 1349, at the death of Angelo di Giovanni di Collebrincioni, the abbot of San Silvestro was appointed executor of his will. He was able to count on a large sum of money to reconstruct the building, which had become necessary after the severe seismic event that occurred during the same year. From that moment on, the bequests to San Silvestro became more conspicuous and numerous, enough to confirm the role assumed by the church as a centralizing pole and a place of reference for the L'Aquila community.

During the earthquake of 1461-1462, sources attest that the stability of the supporting structures was not compromised, despite the collapse of the roof and the bell tower (Colapietra 1978). Therefore, probable restorations were carried out to secure and restore the portions stressed by the seismic event. During the sixteenth and seventeenth centuries, the church underwent simple aesthetic improvements, while, only in 1722, further restoration and consolidation works were carried out. In 1780 the roof was restored, and, according to what was reported, it was the only one in town that was visible (Equizi 1957, p. 115).The last major restoration works date back to 1967 when a radical transformation was carried out by Moretti, who, after the works carried out, was able to assert that only the façade should be attributed to the 14th century, while the central structure could be dated to the second half of the 13th century (Moretti 1972, pp. 690-710).

With a Gothic-Romanesque aspect on the outside and a Gothic-Renaissance one on the inside, in its present state, the building appears as a multi-layered structure strongly altered by the interventions carried out in modern times and by those following the earthquake of 2009, which have partly erased the visibility and the legibility of its external and internal facings.

Figure 2. Historical views of the church dated respectively 1600, late '800 and early '900.

3. Methodology of integrated digital survey of the architectural complex

As mentioned above, the methodology adopted within this research work has set as its first objective the development of a digital survey of the entire structure, carried out through integrated acquisition techniques and intended to provide a graphical basis as reliable as possible from the qualitative and geometric-morphological point of view.

The religious complex of the church of San Silvestro was the subject in February 2021 of a double intervention of non-invasive geometric documentation, carried out in the first instance by Terrestrial Laser Scanning (TLS) and subsequently implemented by a photogrammetric survey SfM developed with photographic captures from the ground and through a UAV device. These were integrated during the acquisition and processing phase and also in their results, to obtain 2D and 3D elaborations at different scales of detail, intended for multidisciplinary applications and analysis (Bertocci et al. 2019). In particular, the main objective of these surveys and digital elaborations was to provide metric-morphological guidelines and digital support for developing the stratigraphic analysis of the complex and its architectural components.

The methodology followed for the elaboration of this digital documentation has provided a preliminary phase carried out on-site to plan the digital survey activities, with particular attention paid to the definition of the flight paths of the UAV. In this regard, it was preferred to carry out the acquisitions in manual mode to have greater control by the operator, given the urban context in which the church is located.[1]

The first operations conducted for the site documentation involved the use of a TLS technology. To acquire the metric and morphological data of the study site, a Faro CAM2 Focus^{M} 70 instrument was used, a laser-scanner with phase-difference technology, through which 59 descriptive scans of the external perimeter of the building and its principal interiors were performed.[2]

The data acquired during the survey campaign using TLS were imported and processed within the Leica Geosystems Cyclone software, through which the main phases of filtering, registration, certification and processing of the global point cloud were carried out,

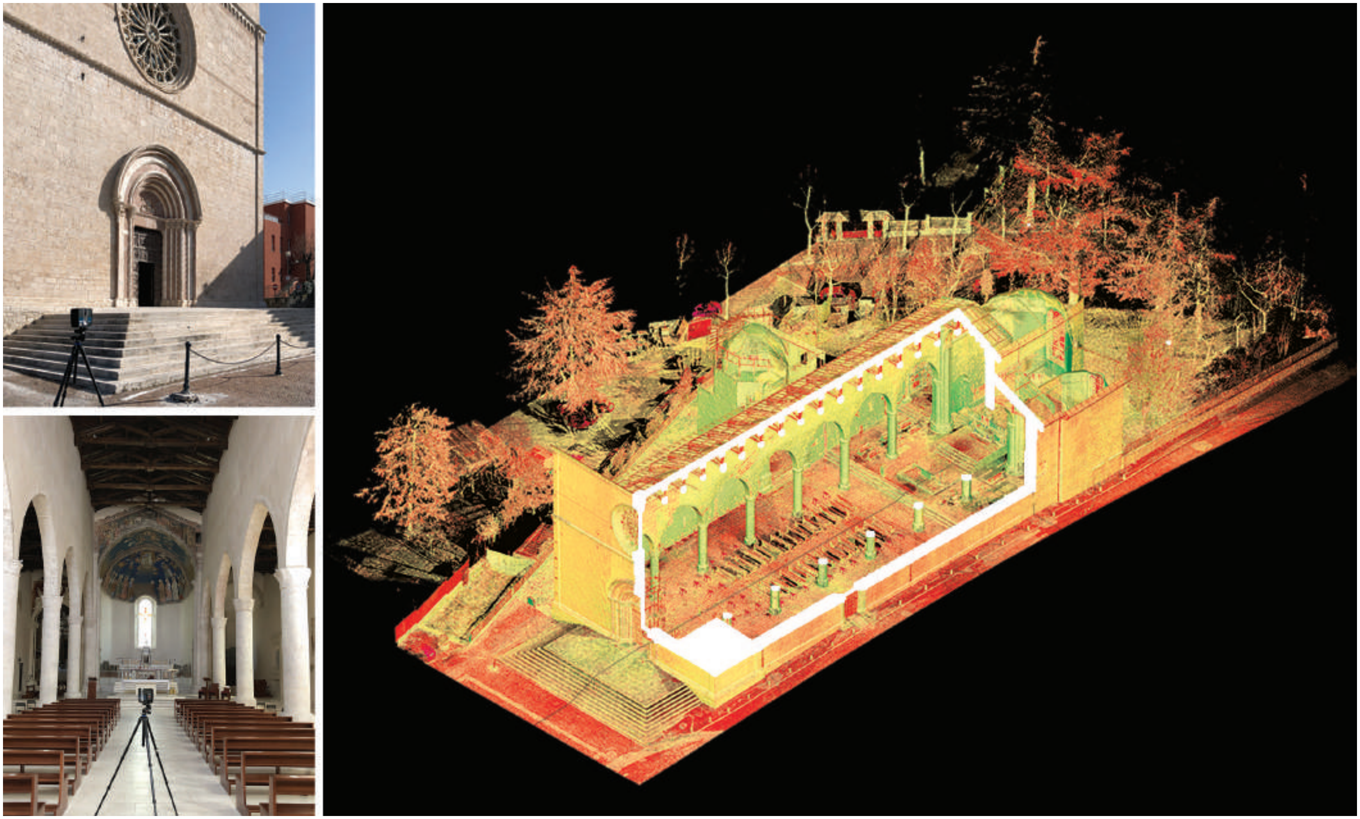

Figure 4. Data acquisition phases using TLS and axonometric cross-section of the point cloud of the Church.

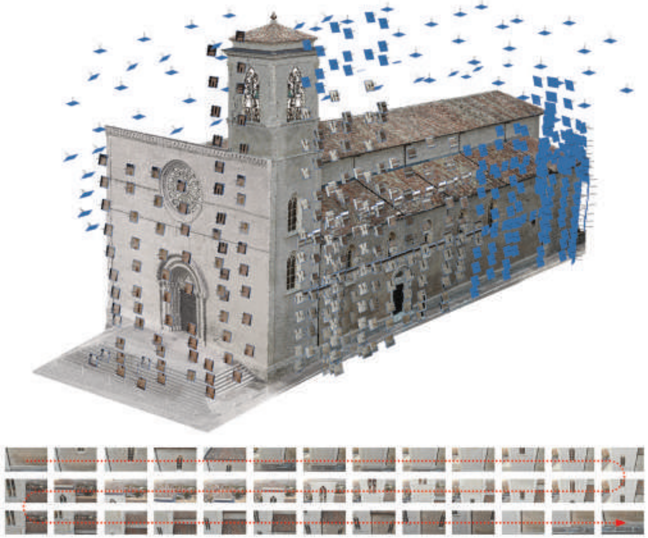

Figure 5. Photographic data acquisition paths using UAV and close-range devices.

according to a methodology widely established by the research team (Bertocci et al. 2021).
Parallel to the development of the laser-scanner survey, a series of SfM photogrammetric survey campaigns were carried out, aimed at integrating the metric-morphological data derived from the point cloud from TLS with a product capable of representing, through mapped 3D models, information about the appearance and the state of preservation of the different architectural elements of the study complex.
For this purpose, different instrumentation and photographic optics were used. Several digital cameras were used for the close-range acquisitions, including a Canon EOS 1100D SLR and a mirrorless Olympus OM-D EM-1 Mark II, with various lenses models. A DJI Mavic Air model UAV has been used in addition to the detailed photographic surveys on the ground to develop the SfM aerophotogrammetric survey of the church of San Silvestro.
The massive acquisition through these devices, with photographic datasets of about 550 photos from drone and 700 from the ground, was carried out to ensure a broad overlap between the various captures to facilitate their integration during the photogrammetric processes.
With a specific focus on the methodology of acquisition and SfM photogrammetric processing of photographic data from the drone, the operational workflow developed by the research group is described below.[3]
Images were taken using the drone's integrated camera at nadiral inclinations, at 45° and orthogonal to the main elevations of the church. The three flights performed lasted approximately 20 minutes each and were conducted at times when there were not too many shadows on the structures.[4]
The photographic data acquired by the drone was subsequently processed within Agisoft Metashape Pro, an SfM photo-modeling software. Through specific SfM processes[5], it was possible to obtain in a short time not only the global textured model from which the orthophoto plans were then extracted, but also the metric mapping in the form of dense clouds of all those upper parts of the church (such as roofs, bell tower and second-order windows) that the TLS survey had not succeeded in acquiring (Ferdani 2020).
These assets were finally referenced and calibrated according to homologous point coordinates extracted from the TLS survey, thus determining the integration between the two digital survey methodologies and obtaining both the mapped 3D model of the church and

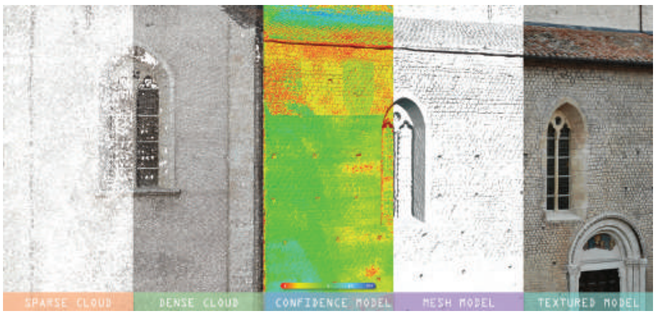

Figure 6. Main photogrammetric processes within Metashape software: sparse and dense clouds, confidence, mesh and textured models.

a global point cloud including the scans from TLS and the dense cloud from UAV.
Through a careful process of data digitization[6] and discretization of these assets, reliable 2D graphic elaborations were produced, mainly including elevations and floor plans in 1:50 scale, both in the form of wireframes and orthophotos.[7]
The corpus of elaborates produced allowed to accurately and comprehensively document the church, both from a metric-morphological and chromatic-material point of view (Minutoli et al. 2020).

4. Archaeological analysis of the architectural complex

The virtual reconstruction of the digital-twin of the church, based on the elaboration of the data developed by the integrated reality-based survey, and in particular on those acquired by the UAV photogrammetry, describing the elevated areas of the church not caught by the laser-scanner, led to the second aim of the research project: the archaeological analysis.
The latter, conducted both on-site and digitally on the graphical drawings, mainly concerned the external walls of the church, the first witnesses of the transformations undergone by the structure over the centuries.
Given the complexity of the structure and its not optimal readability, a diachronic approach was taken, i.e. an initial macro interpretation of the evolution of the artifact was carried out through the evaluation of the stratigraphic relationships established between the different structures[8]: CF1 - Bell Tower[9], CF2 - Church[10], CF3 - Chapel and CF4 - Rectory[11].
In addition to these first investigations conducted on-site, a more in-depth analysis of the architecture and construction techniques adopted was then carried out, focusing mainly on the understanding of the Masonry Stratigraphic Units (MSU) of the east elevation, the only one without plaster and restored more lightly.
The results of such analysis have then allowed proceeding to make targeted comparisons with the other three visible elevations and, consequently, to develop the following hypothesis concerning the identification of the various construction phases of the church:

Phase 1 – n. d.
Probable construction of the present bell tower (CF1).[12]

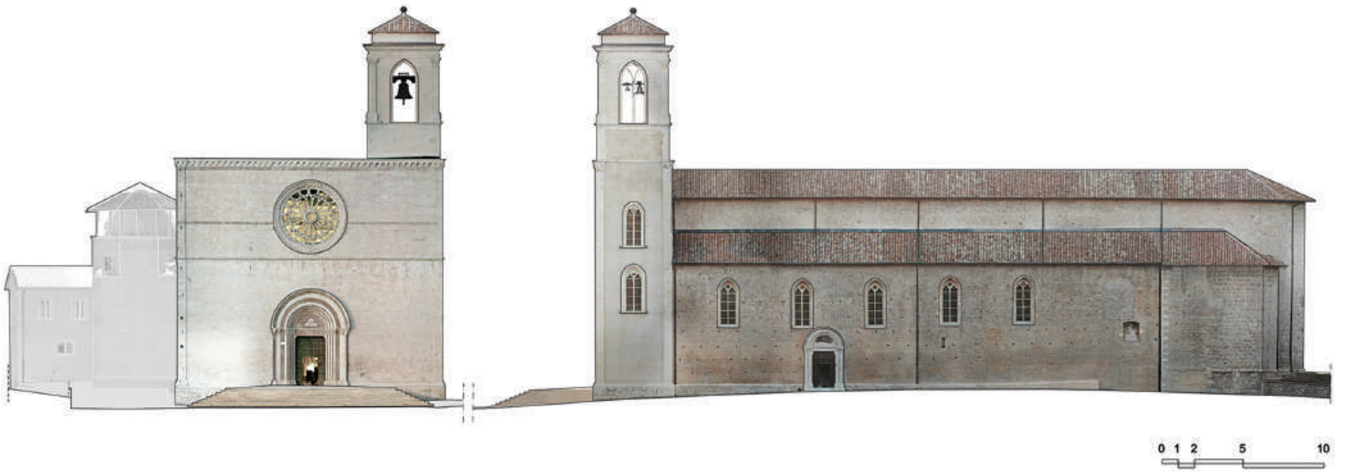

Figure 7. 2D Orthophotoplans of the north and east elevations of the church.

Phase 2 - ante 1265
Probable construction of the church (CF2) with masonry in blocks in support of the pre-existing bell tower (CF1), terminal transept and mullioned windows with two lights (or single lights) on the side elevations. The internal portions, marked by a tripartition of the naves with columns, seem to be those of the first phase, except the presbyterial part built in the following phase.

Phase 3 - 1330
Significant reconstruction of the apsidal portion that redefines the entire presbyterial area.
Two massive polylobate columns are erected, creating systems of arches.

Phase 4 - 1461-62
Another significant modification to the structure with the elimination of the transept, the construction of a connecting wall between the two parts and the displacement of the portal on the east side within the curtain wall of the hypothetical transept.

Phase 5 - XVI Century
The openings of the church are redefined with the creation of large windows on the two levels of the building and the probable displacement of the portal in the central portion of the west elevation.

Phase 6 - 1967-69
The most documented phase thanks to the documents found within the Archives of the Superintendence of L'Aquila.
These documents show how the extensive interventions carried out by Moretti in 1967 brought the church back to its medieval appearance, obliterating the activities carried out in the previous phase, reopening or rebuilding the large windows on the side elevations, and finally, moving the portal to its current position (probably corresponding to the original one).[13]

Phase 7 - post 2009
Realization of small interventions to block some structural degradations triggered by the 2009 earthquake.

5. Conclusions

The results obtained from the research experience presented in this paper have allowed validating the methodological protocol established within the research project on the evolutionary dynamics of L'Aquila's architectural heritage.
The methodological synergy between integrated digital survey techniques, TLS and UAV, and the historical-archival studies conducted, has allowed the development of a rich and reliable palimpsest of documents, graphics and three-dimensional assets, which in turn has become the metric-informative basis for the processing of archaeological and stratigraphic analyses of the church of San Silvestro in L'Aquila.
The potential offered by short-range aerial devices for the acquisition of otherwise inaccessible architectural data, such as the drone used in this case study, has allowed optimizing and speeding up the documentation and knowledge of the structure. The change of perspective offered by a UAV, from frontal to nadiral, leads not only to a shift in scale, from human to architectural, but also to a different perception of the object of study, visualizing it in its entirety and highlighting the stratigraphic relationships established between the various parts of the architectural complex.
The contribution intends to underline how the virtualization of the architectural heritage, especially the one located in seismic areas, carried out through an integrated approach that foresees not only TLS technologies but also the more dynamic one of drones, is configured as a helpful multidisciplinary tool both for the monitoring and the safeguard of the structure, but also for the direct interpretation of its constructive dynamics.

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Andrea Arrighetti wrote the paragraph "Archaeological analysis of the architectural complex" (4), Alfonso Forgione

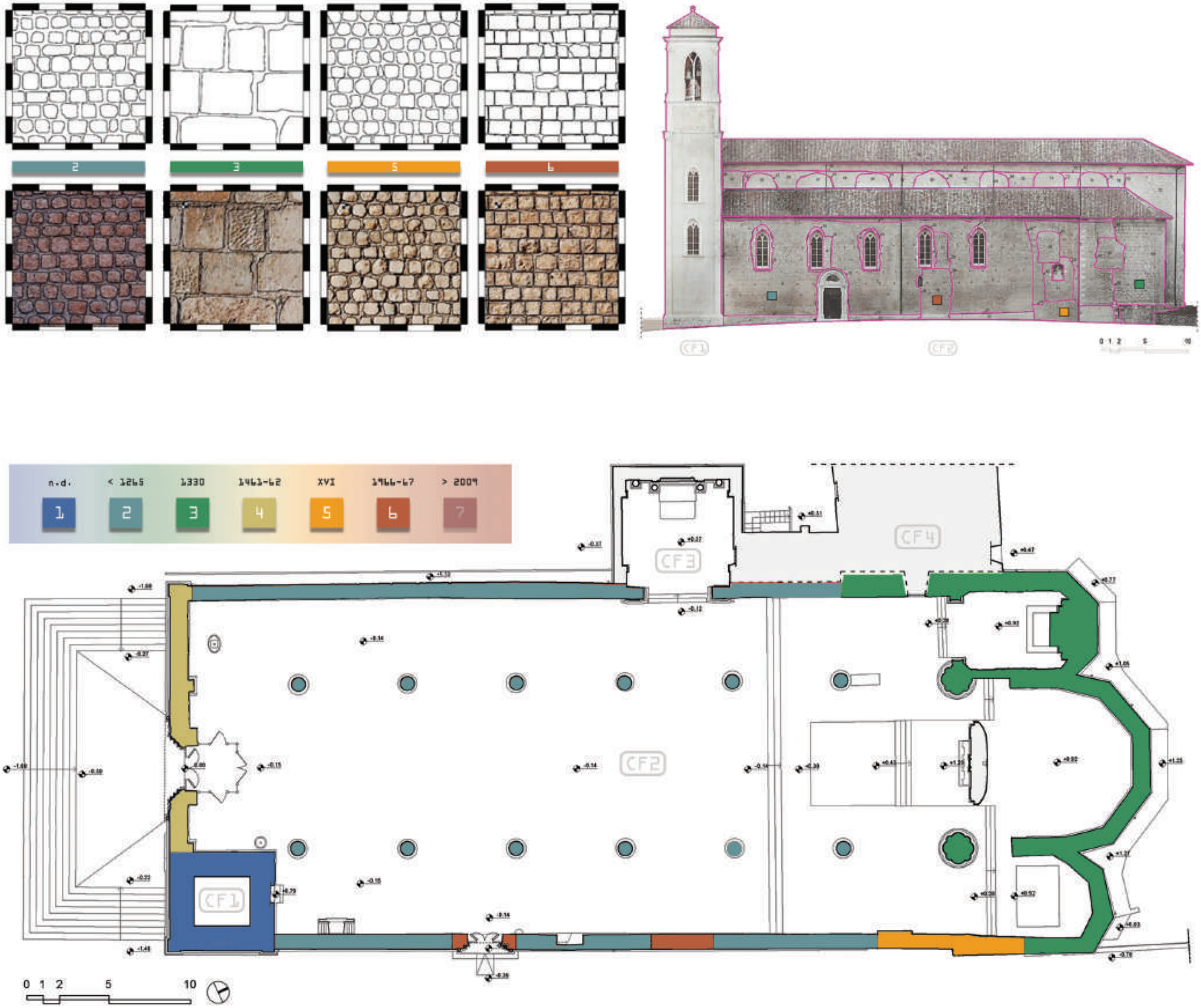

Figure 8. Archaeological analysis: wall construction techniques of the main phases, MSU stratigraphic analysis of the east-elevation and plan of the church's construction phases.

wrote the paragraphs "Introduction" and "The Church of San Silvestro in L'Aquila" (1, 2), Andrea Lumini wrote the paragraphs "Methodology of integrated digital survey of the architectural complex" and "Conclusions" (3, 5).

Notes

1 In this case, it has been chosen not to perform automatic flight by waypoints, although the device had integrated GPS, in order to avoid both possible data missing, but especially potential collisions with the object of the survey or with other neighboring buildings.

2 Between two adjacent scans, an overlap of around 50% of common points was tried to be maintained. These were all processed in B&W, both for reasons of acquisition speed and because the chromatic data would have been integrated later through SfM photogrammetry.

3 Bearing in mind that this will be the same as that carried out for the close-range shots on the ground

4 Mainly around 5 and 6 p.m., considering that the surveys were carried out in February and that this interval allowed a more diffuse light.

5 Once the images were imported, the software, through image-matching processes, identified homologous points between the shots and reconstructed their position and orientation for each one. These procedures have thus allowed elaborating an alignment between the images acquired in the form of a sparse cloud. Through further specific DSM algorithms, this sparse cloud of points was subjected to densification by using all the pixels of the images. The dense cloud points were subsequently triangulated and polygonized, creating a 3D mesh model. This was finally mapped with the texture of the photographs, resulting in a digitally mapped 3D model of the church surfaces.

6 Contrary to the traditional methodology in which the so-called orthoimages referenced by Cyclone software were exported and then proceeded to their digitization in a CAD environment, for this case study, it was chosen to rely on the interoperability of Autodesk Recap Pro and AutoCAD software.

7 In particular, a complete planimetry of the building at the ground floor level (about 1,5 meters from the ground) and four orthophotos related to the external elevations of the structure have been realized. Photoplans of the complex's interior were not taken because, since the walls were covered by plaster, they would not have yielded data of interest from an archaeological point of view.

8 Although the reflections were mostly limited to the exterior elevations, given the extensive presence of plaster that characterized the surfaces of the interior walls

9 The bell tower (CF1) presents well-defined edges and perimeter masonry constructively continuous and very thick (about 1.45m) compared to that of the church (CF2). Therefore, it seems conceivable that it was a pre-existence compared to the church.

10 The church's facade (CF2) presents an extended cut visible on the west side near the cantonal, which denotes its reconstruction later than the masonry. Moreover, the apsidal masonry shows a masonry thickness, a course, and a building technique that differs considerably from the church's perimeter masonry.

11 The areas on the west side, with particular reference to the chapel (CF3) and the rectory (CF4), are visibly leaning against the church's walls. Therefore, as far as it can be seen from the external portion, they are later than the west perimeter walls of the religious building.

12 Probably put in place with different purposes than the religious ones but of which at the moment there is no material or written evidence.

13 These operations are carried out using bare materials and construction materials similar in origin and manufacturing to the ancient ones, even if the construction technique is well recognizable inside the oldest walls.

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