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MULTI-SENSOR SURVEYS FOR THE CHURCH OF SANT'AGNELLO ABATE. 3D MODELS AND VIRTUAL FRUITION

Daniela Palomba, Domenico Iovane

Department of Architecture University of Naples Federico II, Via Forno Vecchio n.36, Napoli, Italy, (daniela.palomba, domenico.iovane@unina.it)

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ABSTRACT:

The proposed contribution outlines the study conducted on the Church of Sant'Agnello Abate, located in the ancient center of the city of Maddaloni. The church is characterized by severe decay conditions and has been inaccessible and unusable for decades. To recover the memory of a place that was habitually used until 1980, survey activities were performed on the building body. Specifically, multi-sensor surveys have been performed and allowed the complete 3D documentation of the building. Various goals were set: documenting the current condition and configuration of the church: creating virtual fruition systems, since the place is closed and characterized by poor safety conditions; establishing communication models, aligned with contemporary iconographic culture, for the appearance of the places before 1980. Both for survey technologies and fruition modalities, low-cost systems were employed and tested.

1. INTRODUCTION

The application of new communication tools to the architectural heritage allows the exploitation of virtual and immersive experiences, aimed at knowledge acquisition and digital fruition regarding the existing building heritage.
This paper shows the results of a research work carried out on the Church of Sant'Agnello Abate (Figures 1-2), in the historical center of the city of Maddaloni, a city in the province of Caserta (Italy). This church is now inaccessible and in a state of severe decay. The building suffered heavy damage in Irpinia-Basilicata 1980 earthquake, and during a snowfall in 1985 that contributed to the collapse of vaults, which had already been highly damaged by the earthquake, and to the failure of the original covering in timber trusses. The abandonment of the site, and the execution of consistent, yet mostly inadequate or unsuitable, interventions, together with thefts and modifications, have led the notable construction to a 40-year-long oblivion.
The research has several goals: documenting the current condition and configuration of the church; realizing virtual fruition systems for a closed site, characterized by scarce safety conditions; organizing communication models, coherently with contemporary iconographic culture, for the appearance of the site before 1980.
The parvis of the church of Sant'Agnello Abate is above the ground level of Via Maddalena, the street it overlooks, while the façade and the bell tower are positioned backward from adjacent constructions. The year of construction is unknown, and there are few historical sources showing that the initial fabrication dates back to the 10th century. The church is composed of three aisles, a cylindrical apse, and four bays delimited by spolia columns; these latter are now visible, but in the 19th century they were incorporated in columns with faux marble lesenes.
Baroque-style interventions date back to 1721, while the 19th century was the age of realization of the lowered barrel vaults, decorated with geometric models, on the ceilings of the three aisles. *Cappella della Madonna de'dolori*, accessible from the left side aisle, was also realized in the 19th century.
The study was developed in several phases, through a consolidated survey methodology. The first phase is based on the in-depth search for documental, bibliographic, and iconographic sources; this is fundamental for a conscious analysis of places, but also necessary for the realization of the virtual models of the appearance of places before the '80s earthquake. The second one

Figures 1-2. Church of Sant'Agnello Abate, Maddaloni.

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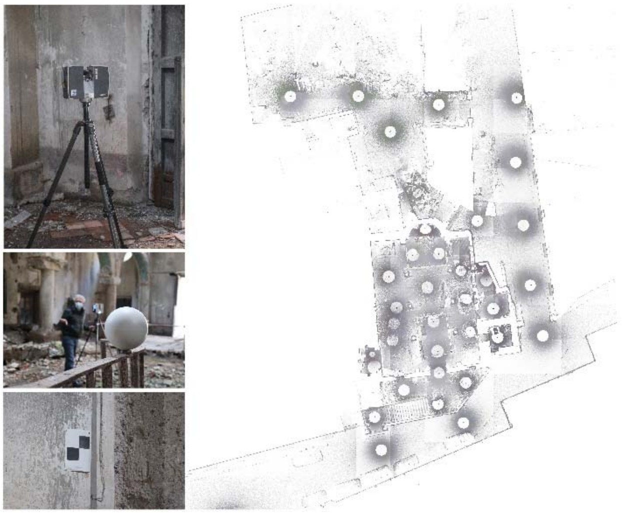


Figure 3. Laser scanning survey activities.

included carrying out multi-sensor surveys, which allowed realizing 3D digital models, serving as digital twins of the religious building. The third phase was the systematization of previous activities for the realization of forms of data archiving and fruition.

2. RELATED WORKS

In the contemporary cultural scene, there is a growing allure toward the multiple knowledge acquisition systems regarding the Cultural Heritage. The development of engaging communication methods and the possibilities offered by more and more innovative and sophisticated technologies encourage experimentation and ideation modalities for knowledge acquisition, dissemination, and education. The current study is part of the field of research aimed at the knowledge and fruition of cultural heritage in general, and of religious heritage

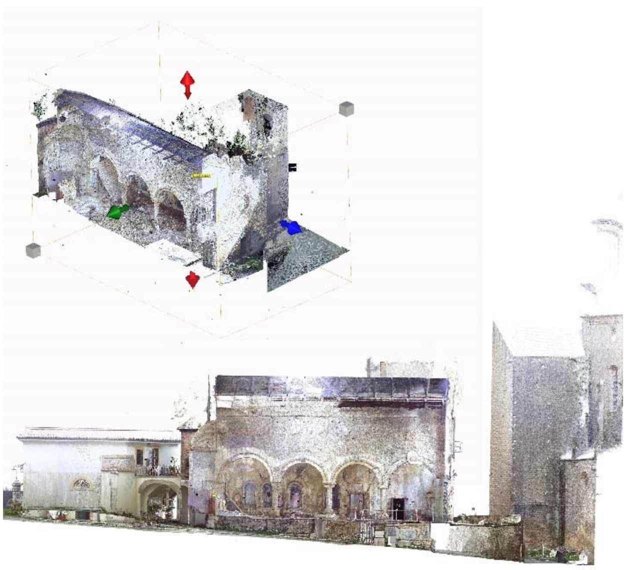


Figure 4. Laser scanning data processing.

(Luhmann et al., 2019; Luigini et al., 2021), with a specific focus on closed and inaccessible artifacts (Alabiso et al., 2016; Dhanda et al., 2019).

The heritage of religious buildings strongly characterized our cities, from smaller ones to those with higher building densities. These architectures differ in style, form, size, and typology, and contribute to the narrative of the identity of places. However, in the vastness of this heritage, estimated to be of around 85.000 churches, those classified as "*religious cultural heritage*", part of the around 100.000 estimated Italian churches, include several cases of unused buildings. These churches no longer have the required conditions to stay open. The reasons for the lack of use are different and are related to both their conservation state, change in needs, and the impossibility to use and manage these places for religious activities.

In recent years, the themes of protection and valorization of religious cultural heritage are becoming more and more relevant in the national and international public debate. Hence, there is an increasing number of projects for the individuation of new forms of use and suitable valorization actions for this heritage.

3. THE APPLIED METHODOLOGICAL PROCESS

Reality-based digital survey techniques can be applied in diversified architectural contexts and allow examining the complexity of the built heritage.

The possibility to acquire 3D spatial data allows generating digital clones, that is 3D models, to represent the surveyed artifacts. The digital survey provides the scientific base for the preparation of study and research and represents an effective dissemination tool for a non-specialistic audience, too (Torres Martínez et al. 2016).

For the church of Sant'Agnello Abate, data from both active and passive sensors were employed. Range-based and image-based integrated methodological processes, characterized by the diversified nature of data, led to the production of high-resolution models.

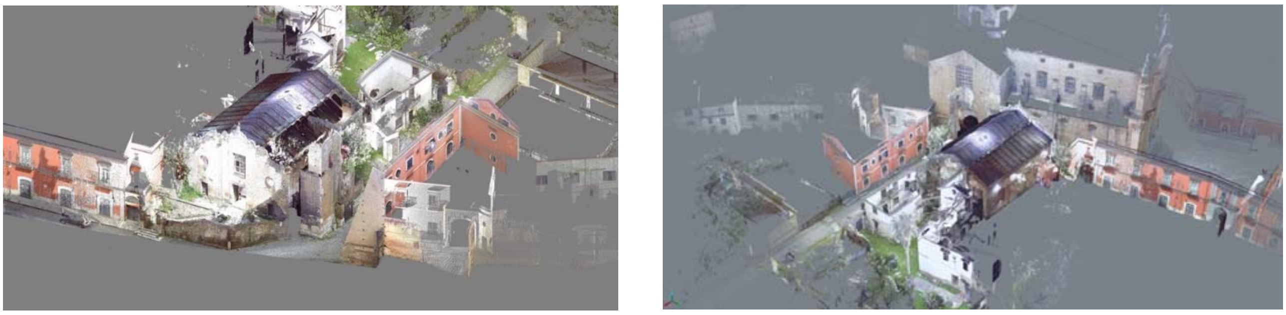
The spatial organization of the places, their relationship with the urban fabric, and the architectural components in the proximity of the church have oriented the process toward the combined use of survey methodologies. In addition to metric and colorimetric data, this allowed the critical investigation of the limits and potential of the employed technologies in relation to their use in complex operational scenarios.

4. MULTI-SENSOR SURVEYS

The methodology adopted is based on consolidated analysis, understanding, and survey protocols. The conservation state of the church and its morphology oriented the choice toward the use of integrated digital reality-based 3D survey methods. Regarding range-based technology, a FARO Focus 3D S120 laser scanner was used, through which morpho-metrical data were acquired both for internal and external spaces (Figures 3-4).

Multi-scalar surveys were carried out with image-based techniques. Aerial and terrestrial photogrammetric surveys were used for inaccessible parts, areas with a severe state of decay, and artifacts that required a focus on a detail scale. A UAS, specifically a DJI Mavic 2 Pro, was used for the documentation of the construction and the adjacent urban context, while terrestrial photogrammetry was performed with GoPro Hero6 Black and GoPro HERO MAX 360° action cameras.

All the technologies and tools employed allow producing 3D models to describe the metric, geometric, and colorimetric characteristics of the surveyed artifacts. Nowadays, it is a



Figures 5-6. Point cloud from laser scanner survey.

common practice to use them simultaneously to compensate for their respective specific limits, which any technology has, and reduce their criticalities. Thanks to the high acquisition rapidity, and hence to the possibility of dedicating lower time to survey phases, the employment of these technologies results to be particularly effective in vulnerable contexts, which are also characterized by poor safety conditions. The time factor (a parameter that is obviously evaluated in relation to data quality and quantity), is moreover compounded with the saving produced by the economic investment when considering low-cost equipment, as for *image-based* survey. In this last case, thanks to the use of increasingly accessible sensors, in addition to the implementation of image-matching algorithms and use in Structure from Motion software tools, multi-sensors result to be increasingly diffused and effective in the generation of photogrammetric 3D models (Calantropio A. et al., 2018). Survey activities for the documentation of the church of Sant' Agnello Abate were carried out in two days. The first day was dedicated to the range-based survey, whose design and realization took 6 hours. The second day was dedicated to the image-based survey of the external area and the detail-scale elements inside the church. Surveys with a UAS – Unmanned Aircraft System – took 70 minutes overall, while 2 hours were dedicated to terrestrial photogrammetry, performed on the 6 spolia columns and other details inside the church (some flooring details and the altar). In the end, all the morphometrical data, despite the several criticalities of the context, were acquired in little more than 9 hours of reality-based survey activities.

5. THE SURVEY CAMPAIGN AND DATA INTEGRATION

For the TLS survey, a FARO Focus 3D S120 scanner was employed. The survey planning envisaged the complete investigation of all the built elements, documenting both the external and internal configuration. The acquisition modality was based on consecutive scanning.

The survey project led to the acquisition of a total number of 36 scans, with 1/8 resolution and 4x quality as settings.
The choice of the station points was aimed at acquiring as many visible elements as possible from each scan and reducing shadow areas.
All the acquired scans were oriented according to the same reference system, as suitable overlapping between adjacent scans was guaranteed, allowing the recognition of common points to perform spatial roto-translations.
Most roto-translations were performed automatically by the software tool, through the recognition of pre-signaled homologous points, that is the plain and spherical targets used in the survey phases.
The registration phase, as well as all the scan processing and cleaning phases, was performed in the proprietary software of the laser scanner, Faro SCENE. 4 hours were employed for preliminary processing, point cloud processing, and orthophoto extraction (Figures 5-6).
Scanning was performed by correlating the scans of internal spaces with those required to survey the external configuration. To integrate the data from two different technologies, hence defining a single reference system, the laser scanning of the external spaces considered photogrammetric targets.
Data from TLS activities were integrated with a photogrammetric survey, which allowed the acquisition of both roof coverings, and detail-scale elements.
A UAS unit, that is DJI Mavic 2 Pro, was used for the survey of the building and the surrounding urban context.
The photographic datasets were obtained with different acquisition modalities: programmed flight and manual flight.
The programmed flight was performed through the app PIX4Dcapture, setting the double grid mode for image recording, and the different parameters according to the quality and accuracy required for the model to be elaborated.
The flight mission was programmed with the following characteristics: acquisition area around 69 x 71 m, 80% overlap, 60° tilted camera, 60 m flight altitude, 305 total photos, 12 min 30 s. flight time, and 1.62 cm/pixel GSD (Figure 7).

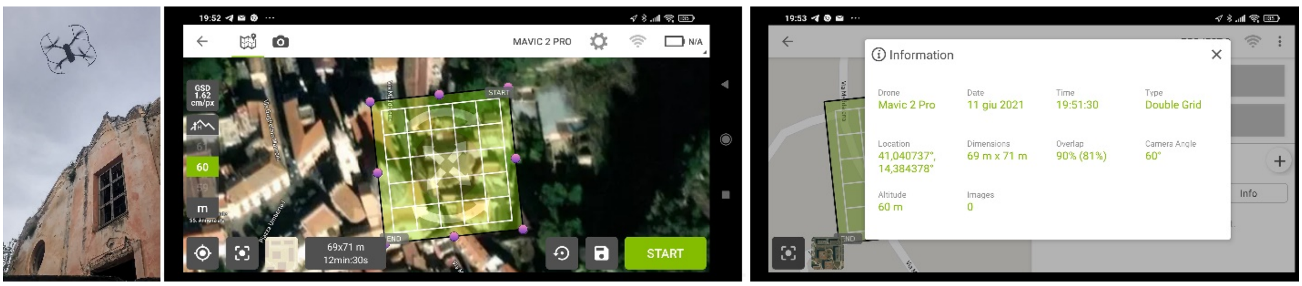


Figure 7. Drone photogrammetric survey activity. Flight programming.

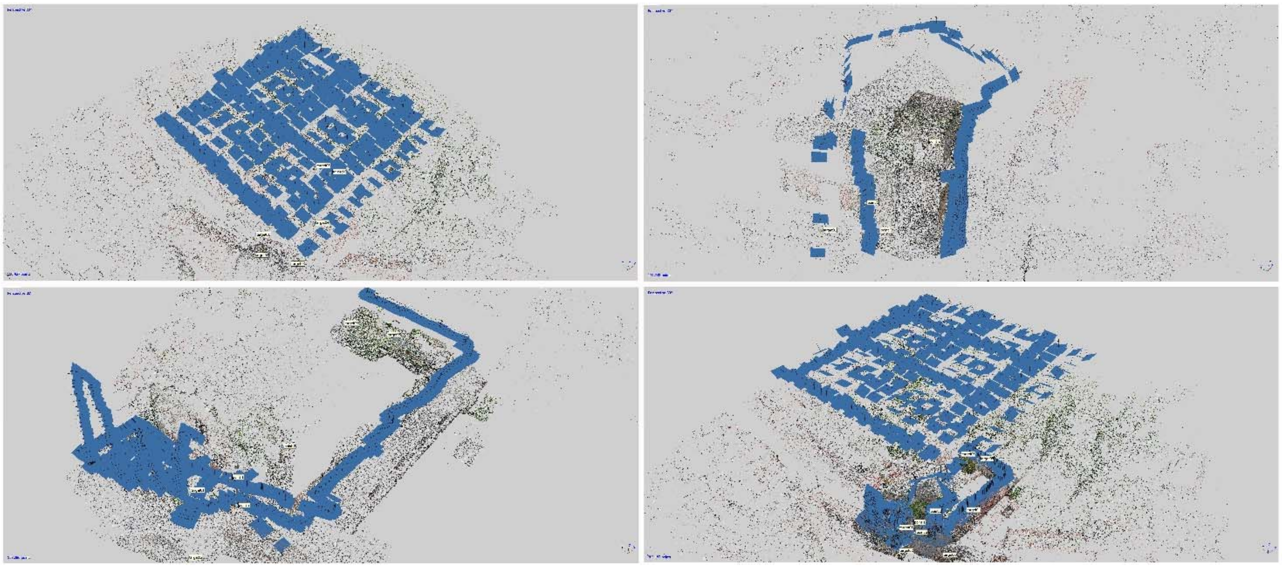


Figure 8. Photographic datasets processing: the area surrounding the church, bell tower, external prospects.

In addition to the roofing system of the religious building, the programmed flight also allowed surveying the wide area where it is located. This acquisition allowed relating the church with the territory; in particular, it allowed highlighting the connections with the nearby Piazza de Sivo and Basilica of Corpus Domini, which majestically and impressively dominates the area. The right aisle of the Basilica is located in front the façade of the Church of Sant'Agnello Abate, which is humbler. The presence of narrow streets and buildings in close proximity to the surveyed one, in addition to the position and configuration of the bell tower, has guided toward the choice of performing two manual flights, too.

The manual flight was employed for two missions related to the acquisition of photograms to survey the main and the side front, and the whole bell tower.

The acquired photographic datasets consist of 510 photograms for the two fronts and 210 photograms for the bell tower, with an average overlapping of around 60% (Figure 8).

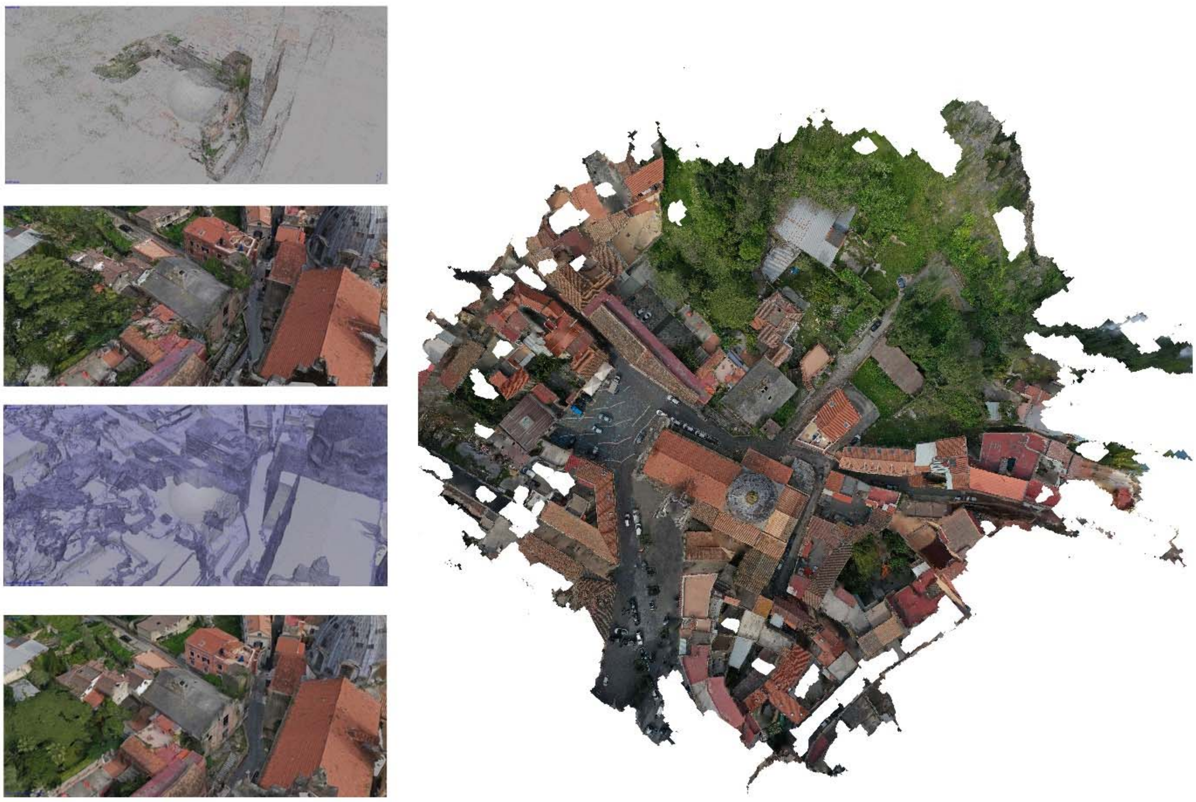


Figure 9. Photogrammetric survey data processing in Metashape.

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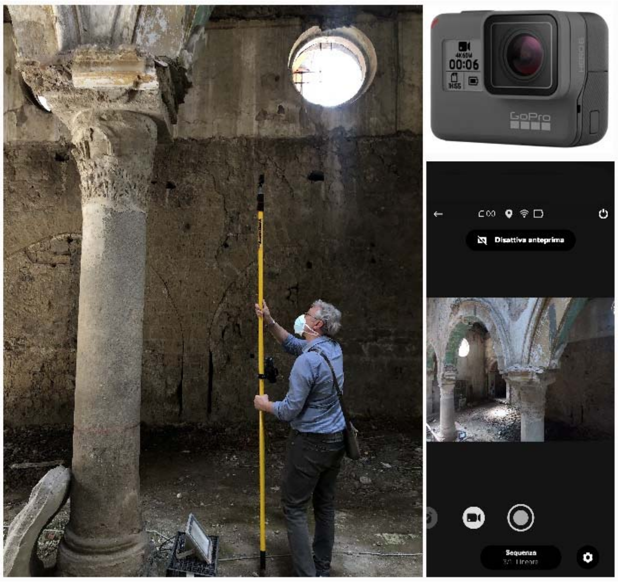

Figure 10. Terrestrial photogrammetric survey activities.

All the photographic datasets, organized into different chunks within the same photogrammetric project, were processed in Metashape, with Self-Calibration Bundle Adjustment. In this case, the correspondence search was based on the use of specific targets located on the scene for photogrammetric acquisitions.
Then, a coarse cloud of 385,187 points was processed.
The following processing phase included the production of a dense polygonal model of 119,323,730 points, and then a triangular mesh of 7,954,913 faces and 4,015,794 vertices. (Figure 9). The whole processing took around 6 hours overall.
The photogrammetric technique was applied, also on a detail-scale level, to improve the study of some internal architectural elements of the church. Specifically, all the columns were surveyed to document the configuration and geometric articulation of their bases, shafts, and capitals. The photographic equipment for the survey campaign consisted of an action cam, that is a GoPro Hero6 Black (Figures 10-11).
The camera was used with various supports, employing both telescopic rods with different lengths, and mini tripods, with different sections, to favor their use in different scenarios. Considering its technical specifications, the employed camera always shot the photographic datasets with a fixed focal length, in compliance with the photogrammetric technique. The photographic datasets from the terrestrial photogrammetric survey, too, were processed in Metashape, employing around 5 hours for point cloud processing (Figure 12).

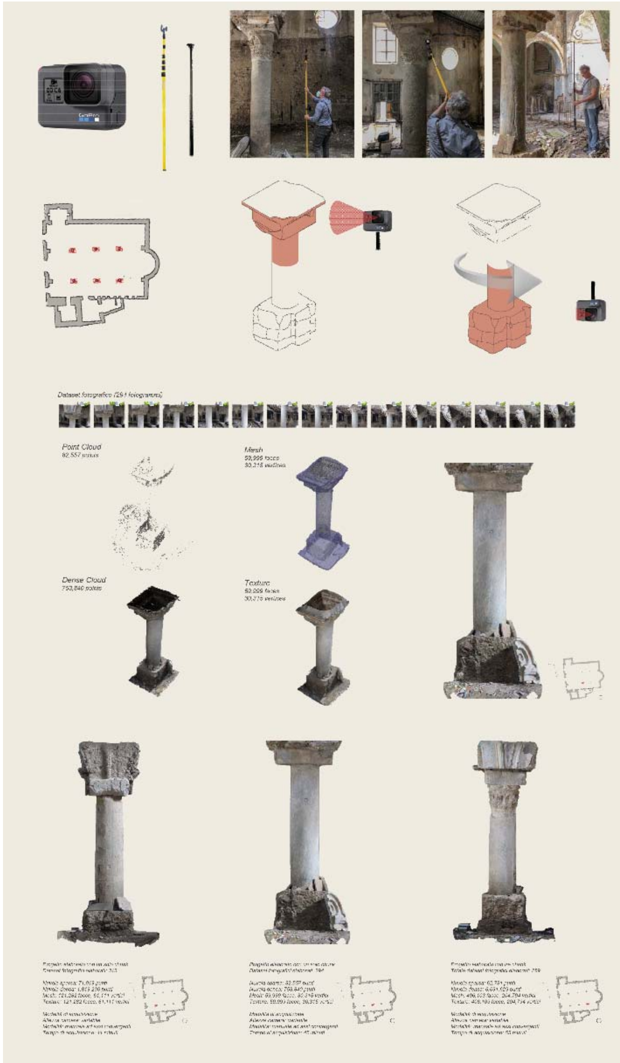

Figure 11. Photogrammetric survey of the columns.

The 3D digital representations of the different parts were metrically scaled and oriented to obtain a single model for the representation of the place.
Finally, spherical photos, realized with the action cam 360° GoPro HERO MAX, were recorded in an ordered and pondered way, to be used in a virtual fruition project (Figures 13-14).

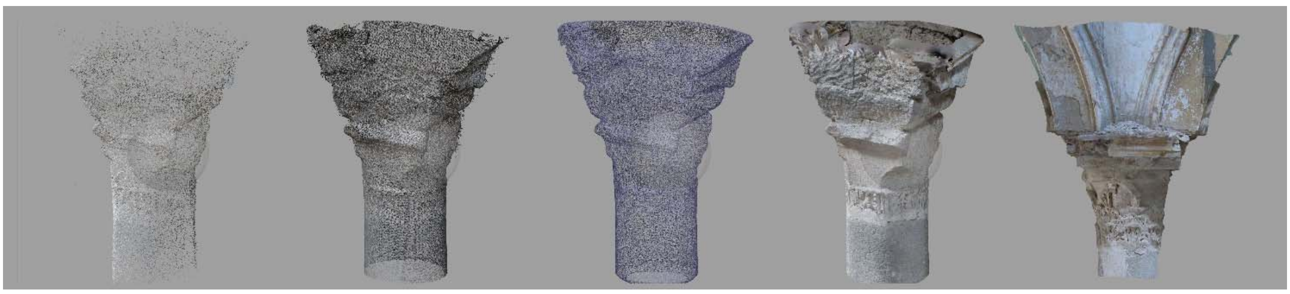

Figure 12. Processing of the photographic datasets of the internal capital.

Figures 13-14. Spherical and tiny-planet photographic dataset acquisition.

6. RESULTS

Through an accurate site survey, in addition to documentary and bibliographic research, it has been possible to individuate and reconstruct the pre-earthquake appearance of the site (Bevilacqua et al., 2019) (Figure 15). Several results have been achieved: in first place, an original digital and graphical 3D documentation, which details the current condition and configuration of the church. In addition, 3D representation models of the main transformation phases of the church have been realized. Moreover, looking forward to a restoration aimed to return the religious building to the community, some possibilities for the virtual fruition of the site have been devised, also considering its now-decennial closure for its devotees and the impossibility to envisage the accessibility to the church, at least in the short term. The idea is to virtually open the gate of the church, both unveiling its current image – which is unknown to most – and enriching the virtual experience with the indication of points of interest – POI – to access the various typologies of information content. The achieved result is represented by a *web map,* which is accessible through mobile devices and downloadable through a QR code located near the access to the parvis of the church.
The *ex-ante* design of the virtual tour also affected the modalities and the organization of instrumental surveys, planned and performed in accordance with its envisaged final result, both concerning the data typology required by the research goals, and the accuracy required for the correct documentation of the site. Also for this last goal, it is possible to employ low-cost tools and open-source programs to generate and manage virtual tours.
For the structuring of the fruition project, accessible on a website through a web browser, it was chosen to use the open app *Marzipano* (Figure 16), which allows creating virtual tours based on the acquired data, and/or on data deriving from the previous survey and documentation phases. Hence, a visit route was

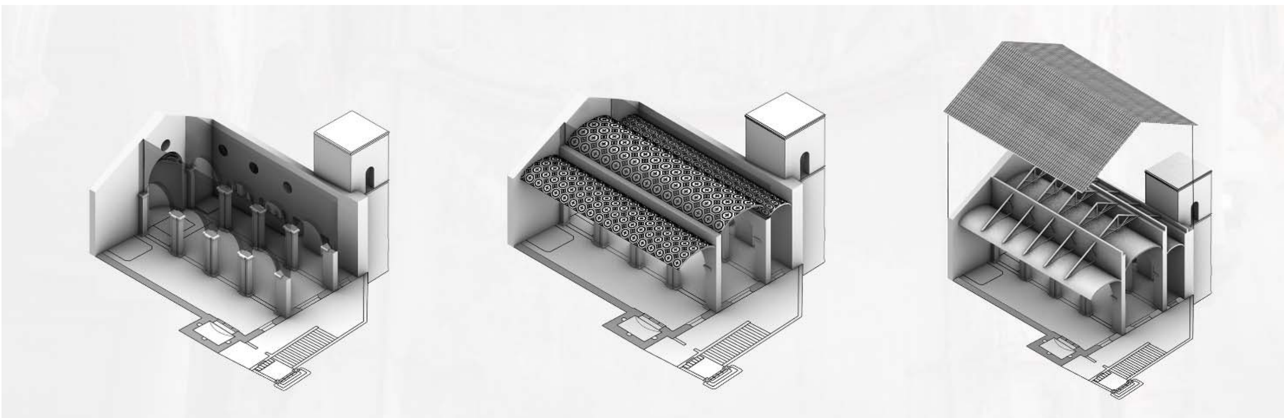

Figure 15. Model of the church pre-earthquake. Graphic elaboration by Mariarosa Sarracco.

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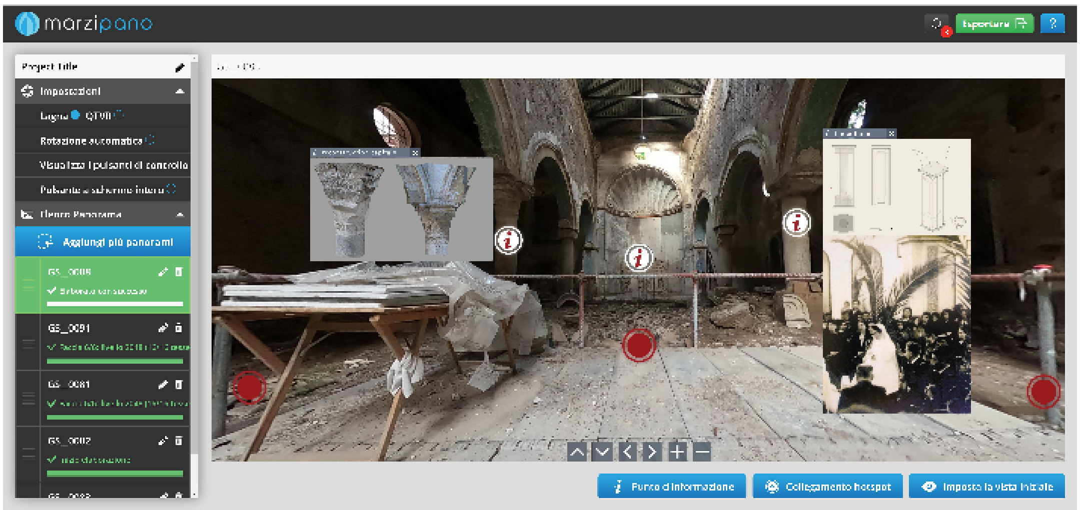

Figure 16. Tour virtual design with Marzipano.

designed and realized to enjoy the virtual space and interact with *infospots*, which allow expanding users' knowledge by *increasing* the information on the church and the elements inside it. The platform allows uploading spherical photos to be explored in virtual tours. The employed photos include both the equirectangular ones, acquired through laser scanning and opportunely edited, and the ones acquired through the GoPro HERO MAX.
This will allow enjoying an experience of site exploration through spherical images, 3D digital models, graphical drawings and pictures that detail the building and its transformations. The last goal has been the realization of digital models for the description and representation of the appearance and the configuration of the building, in its state before the seismic event produced severe damage. Finally, also these models were linked with the *infospots*, strategically located along the tour, to visualize the image of the pre-destruction church, starting from the position to which the model views are referred (Figures 17-18).

7. CONCLUSIONS

The project is part of a field of research and experimentation related to the individuation of methodologies to share cultural contents as much as possible with a wide and heterogeneous audience, without indulging in sensationalism, as this tendency characterizes, often in a sterile way, the use of digital technologies. The goal of the research is to allow, although virtually, the access to a closed place, researching its history, revealing its events and rarities, re-evoking and rediscovering its former glory.

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Figures 17-18. Virtual tour navigation with insights on point of interest.

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