ISSN 1828-5961

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Drones for survey in the field of restoration: a multidisciplinary approach to the preservation of cultural heritage

The use of drones in the field of cultural heritage is increasing thanks to the possibility offered by these tools to acquire, information on those parts of the buildings that are difficult or impossible to access, so they can be a valid tool to support the knowledge of historical heritage.
The paper presents the results of a multidisciplinary research work conducted on a case study located in Fisciano, Italy regarding the abandoned “Madonna del Fieno” chapel. Built around the fourteenth century, it has undergone several extensions, restorations and transformations. Currently it is in a generalized state of decay as the complete absence of the roof has exposed the environments to atmospheric agents with the consequent occurrence of related decay phenomena.
The study started from the integrated digital survey of the Church that involved the joint use of laser-scanning and aerial and terrestrial photogrammetry. The use of UAVs was essential to obtain a complete and effective survey of the building.
Using integrated three-dimensional survey techniques, two-dimensional graphics were obtained (floor plans of the area, plans, sections, elevations and orthophotos), thus updating the existing graphic documentation of the site. This documentation has constituted an important and essential tool to support the understanding of the complex with a great impact in the process of “interdisciplinary” analysis and interpretation of the building aimed at both knowledge and design.

Keywords:
Conservation; documentation; material survey; church; photogrammetry

DOI: https://doi.org/10.20365/disegnarecon.29.2022.14

INTRODUCTION

The possibility of obtaining high resolution orthophotos of architectural surfaces is crucial for the analysis of the current state of historical buildings, for the understanding of their stratigraphy and, consequently, its 'values' which are the basis of a restoration project scientifically grounded and culturally forward-looking.
This work [1] aims at showing the challenges in the use of modern 3D survey technologies, including drones. They can be a valid tool to support the knowledge of historical heritage, provided that the importance of good programming and of a strongly multidisciplinary approach to the survey project aimed at conservation and restoration. For this purpose, advanced digital survey instruments and techniques have been combined, such as laser-scanner (TLS) and photogrammetric methodologies, through the acquisition of images both on the ground and aerial by UAV.
The case study on which the methodology was tested is an ancient building located in Fisciano, Italy, namely the abandoned "Madonna del Fieno" chapel.

Built around the fourteenth Century, together with the bell tower, the crypt and the adjoining rectory, the building constitutes an architectural palimpsest. In fact, over the time, it has undergone several extensions, restorations and transformations up to the earthquake of November 1980 which caused several damages, made even more serious by the state of abandonment in which the building has poured to date (Fig. 1).
The study took what was largely experimented in some Unesco site (Bertocci & Parrinello, 2015) in archaeological sites and for the landscape documentation (Limongiello & Barba, 2020) and in particular in the archaeological area of Pompeii during the Knowledge Plan of the Great Project Pompeii (Osanna & Rinaldi, 2018).

THE CASE STUDY: THE "MADONNA DEL FIENO" CHAPEL IN FISCIANO

The building is located in the historic centers of Fisciano, Italy. The first documentary records date back to 1309 (Amelio, 1994), when the building was certainly smaller than how it is in the current condition.

To meet the needs of a growing community it underwent several transformations over time. They mainly date back to the nineteenth century and regards the expansion of the church, the construction of a central partition, of a decorated ceiling and the modification of some openings. The Chapel turns out to be a sort of small hidden jewel, very close to the inhabited area, but at the same time not directly visible from the main roads, and, however, isolated from the rest of the surrounding buildings, with a splendid view over the valley and the rural landscape to the North (Fig.2).
The complex can be divided into four parts: the Chapel, the bell tower, the rectory and the crypt. Each of these parts is located at a different altitude. In fact, between Via Cappella, which delimits the complex to the South, and Via Rio Secco, which delimits the complex to the North, there is a jump in height of more than 5 meters (Fig. 3).
This condition of the site combined with the need to know the variations in wall thicknesses, misalignments and all those signs that tell the history of a building, have made the use of integrated survey techniques indispensable and essential.
In fact, all the information collected constitutes the graphic documentation, which was previous-


Fig. 1 - The church of "Madonna del Fieno" and its context


Fig. 2 - East facade of the complex


Fig. 3 - North facade of the complex

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ISSN 1828-5961

ly non-existent of the building, and the scientific starting point on which the restoration and consolidation project of the entire complex was built.

THE INTEGRATED DIGITAL SURVEY OF THE COMPLEX FOR DOCUMENTATION

The expression 'integrated survey' is used to describe an approach that simultaneously exploits several different theories and technological applications during survey and restitution to elaborate a scientifically valid product thanks to their synergetic use (Baglioni & Inglese, 2015).
The study started from the integrated digital survey of the Church to obtain updated and scientifically verified drawings. In particular, the survey involved the joint use of laser-scanning and aerial and terrestrial photogrammetry (Fig. 4).
The use of Unmanned Aereal Vehicle (UAV) is essential to obtain a complete and effective survey of the building since, due to the conformation of the site on which the building stands, three of the four facades are inaccessible for a survey from the ground so it allowed to integrate all those parts that the laser-scanner had not been able to acquire, such as the entire covering and the top of the bell tower. UAV also allowed the extrapolation of high resolution orthophotos, indispensable for the investigations on historicized matter, the diagnostic analyses of materials, decay and instability, and the stratigraphic analyses (Bertocci et al., 2021). Moreover, it allows to detailly investigate the building crests, the bell tower, and the part of collapsed roof without excessive costs. This information is of paramount importance for the development of the structural project.
The acquisition phase involved the use of the DJI Spark drone. For the acquisition of the surfaces, two type of flight are prepared: a first one for the acquisition of nadir photogrammetric images and a second one, with the optical axis tilted about 45 degrees, to survey the vertical walls and any shadow cones. The first type of flight is used for the survey of the crests of the walls and to integrate the data of the undetectable areas with the laser scanner survey. The second type of acquisition is aimed at creating high resolution orthophotos

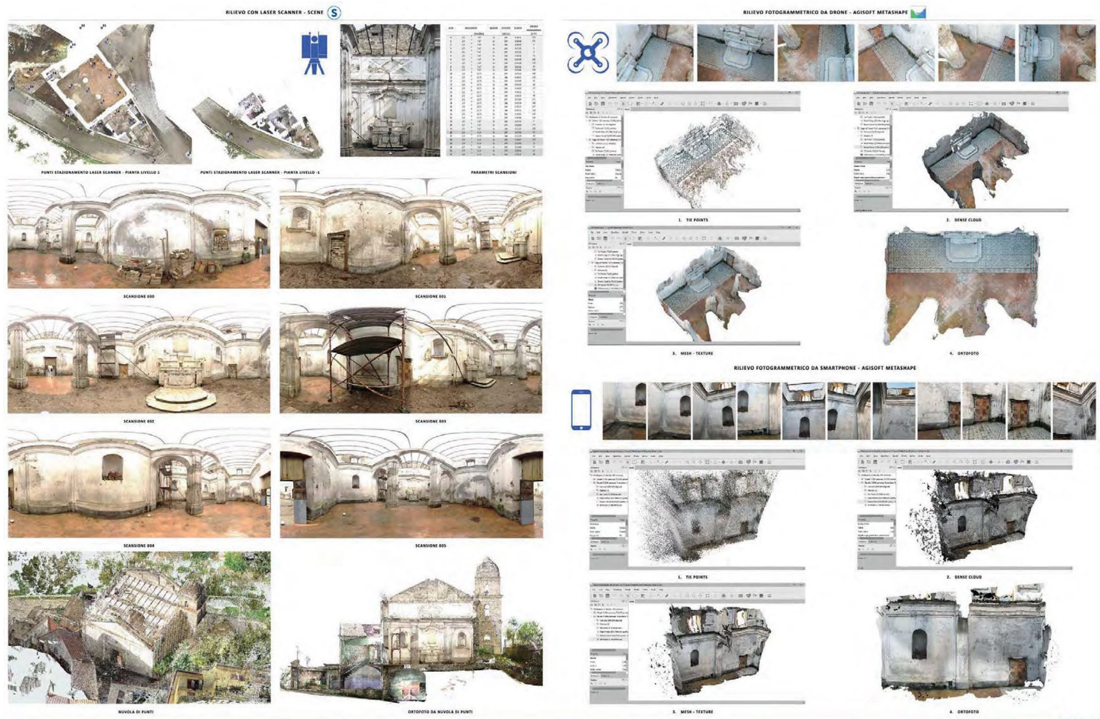

Fig. 4 - On the left, graphic elaboration of the of the point cloud obtained by the laser-scanner digital survey. On the right, 3D models processed by photogrammetric techniques, carried out through drone and camera acquisition

for the subsequent graphic restitution of material survey of three of the four elevations of the building. The flight plans were designed considering the expected GSD (at least 6 mm/pix for 1:50 scale representations), the technical characteristics of the photographic sensor (12 MPx with 1/2.3" CMOS sensor) and the desired overlap between consecutive shots (at least 70%). The post-processing phase, aimed at obtaining a three-dimensional model of the facades, of the pavement and of the walls crests was managed through the software Agisoft Metashape.
The point cloud thus composed was aligned using markers positioned on the morphological points of the architecture and homologous to those deriving from the acquisition campaign database using TLS instrumentation, to obtain a model of the facade properly scaled based on the point cloud laser scanner.
Instead, terrestrial photogrammetry was used to create high-resolution orthophotos of the high interiors, of the main facade of the church and some valuable elements, such as the main altar.
Besides, to obtain a complete model of the object of study, a laser scanner survey was carried out. For the morphological survey of the entire church, a Faro Focus 3D X 130 laser scanner was used which, in optimal environmental conditions, guarantees a scanning range between 60 cm and 130 m, a measurement speed of up to 976,000 points

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per second and a linearity error between -2 and +2 mm. To facilitate the subsequent phases of data processing (registration of the point clouds), spherical targets (six, placed each time on horizontal surfaces) were used, arranged at different altitudes and in intervisible areas in multiple acquisitions. A total of 33 scans were performed, with variable resolutions depending on the distance of the laser from the surfaces, on average equal to a point hit every 6 mm at a distance from the emitting source of 10 m from the object.
The laser scanner model and the one obtained from the drone survey were aligned in the 3DF zephir software using homologous control points identified manually on the two point clouds. The three-dimensional infographic model of the entire church was generated by managing and applying well-established and reliable software procedures and computer algorithms for alignment and filtering. The cloud of points, appropriately treated, made possible to view plans at various levels, cross and longitudinal sections, internal and external elevations, architectural details and to carry out measurements (linear, superficial, and volumetric) with a very high precision. In this way it was possible to carry out a first critical analysis directly on the three-dimensional replica of the building.
The careful survey also allowed to highlight the construction irregularity of the building, which should not be considered as the "degradation" of a design idea due to the imprecision of the construction site, but a peculiarity of the buildings of the built heritage.
The geometrization and rectification that are usually applied in the graphic representation of structures without or almost without rectilinear walls or rigorous symmetries, in fact, can be misleading for the study of historic buildings.
The exact formal digitization of the architecture is essential to bring out non-deductible information, such as even minute variations in alignments and wall thicknesses, existing or presumed anomalies, and chromatic aspects of the surfaces. Their identification and interpretation are fundamental for the analysis of the architecture, the building history, and its evolution. The progress compared to the traditional research methodology is remarkable both for the accuracy of the final data and for the quantity and quality of information available.

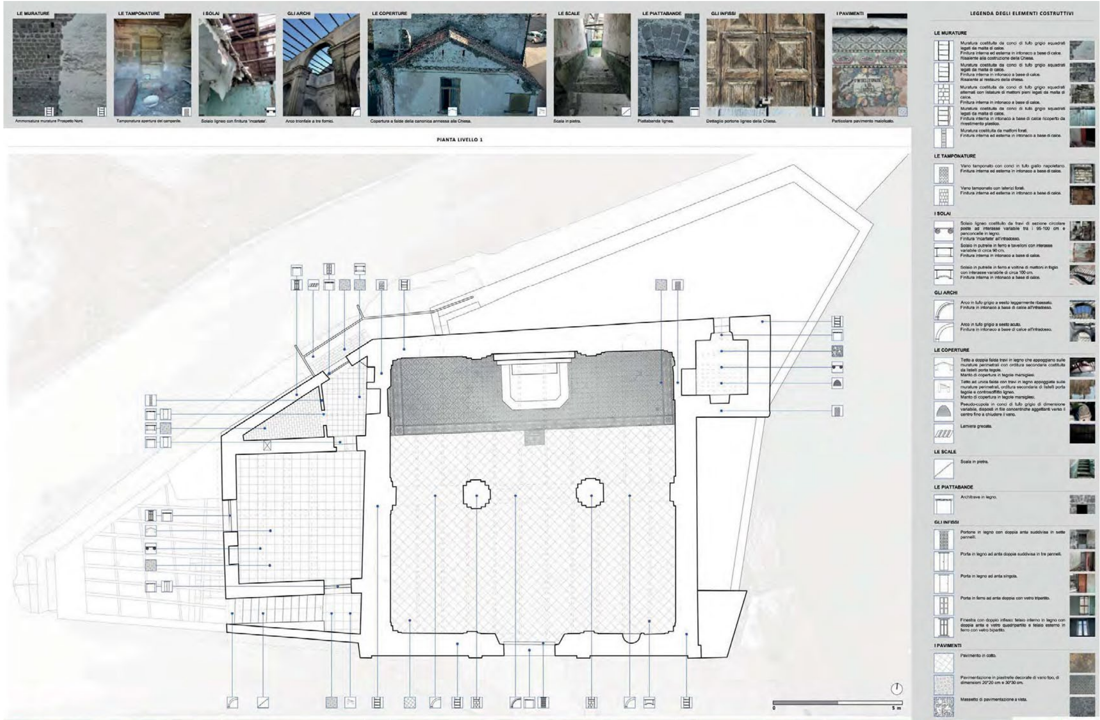

Fig. 5 - Plan section of the church with the identification of constructive elements of the building developed by the integrated digital surveys

RESEARCH RESULTS: OUTPUTS AND HISTORICAL RECONSTRUCTION

Through an extensive documentary research integrated with innovative data collection and processing techniques, a critical approach to the historical heritage analysis and documentation has been implemented. From the point cloud models, plans and sections at significant elevations were extracted and subsequently vectorized in AutoCAD (Fig. 5). The projected elements were drawn starting from the orthophotos of the elevations. It was thus possible not only to have the digital replica of the building available, on which to reason and define project hypotheses, but also and above all the scientifically controlled and complete graphic rendering of the entire complex. The drawings formed the graphic basis on which various analyzes were carried out: those typical of the restoration practice, i.e. the study of the construction elements and the material survey (Figg 6-7), the analysis of decay and the identification of surface conservation interventions and those aimed at structural consolidation interventions of the walls and at the project of restoration (Fig. 8).

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Fig. 6 - Orthophoto and material survey of the north elevation of the church

Fig. 7 - Elevation view of the main development phases of the church

Crossing the archival and historical data with the information coming from the materic surveys is possible to make a hypothesis regarding the historical evolution of the complex over the centuries and to divide the construction processes into 4 phases (Fig. 9).

- XIV century: on the North and West elevations there are clearly visible traces of the first plant of the Church, which had a much smaller volume than the present one. On the North elevation the traces of the initial plant are visible thanks to the presence of a plastered part that corresponds to the North elevation of the old Chapel. Moreover, on the West elevation, it is visible the limit of the previous walls and an opening, now walled up, which was a window, having a lowered arch and a tuff frame. Both floors of the rectory house probably date back to the same century;
- Centuries XV-XIX: in this period the Church underwent some enlargement interventions, probably to meet the needs dictated by an increase in population density in that area (Crisci & Campagna, 1962). The Chapel was transformed by enlarging the previous rectangular plant and transforming it into a square plant, like the one visible today. The openings dating back to this phase are on the East and West walls. These openings are no longer visible, because they have been, over time, closed up, but had a slightly different shape than

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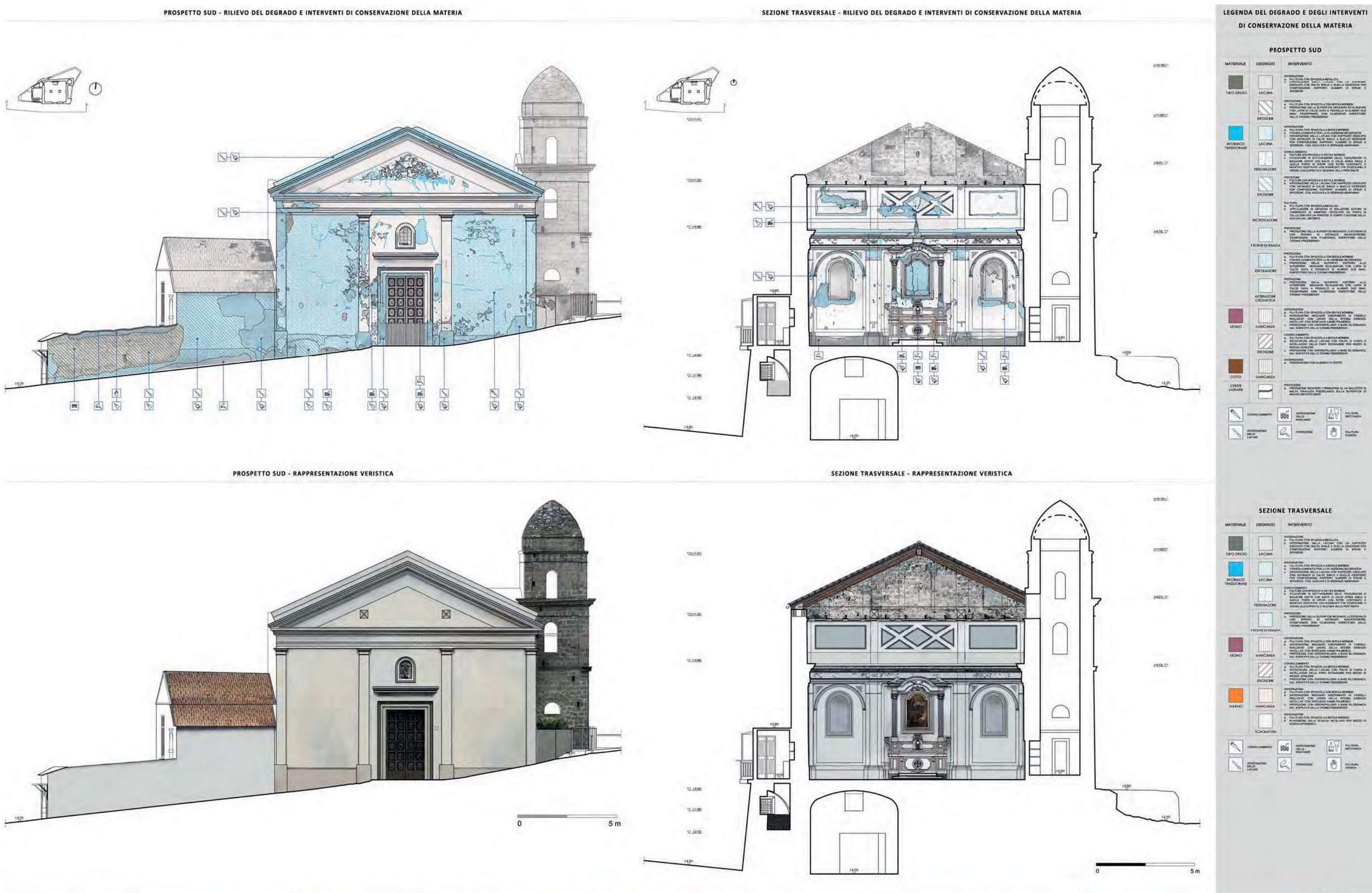

Fig. 8 - At the top the elaboration of analyses of decay of a facade and a section of the church, at the bottom the realistic retitution of the restoration project

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ISSN 1828-5961

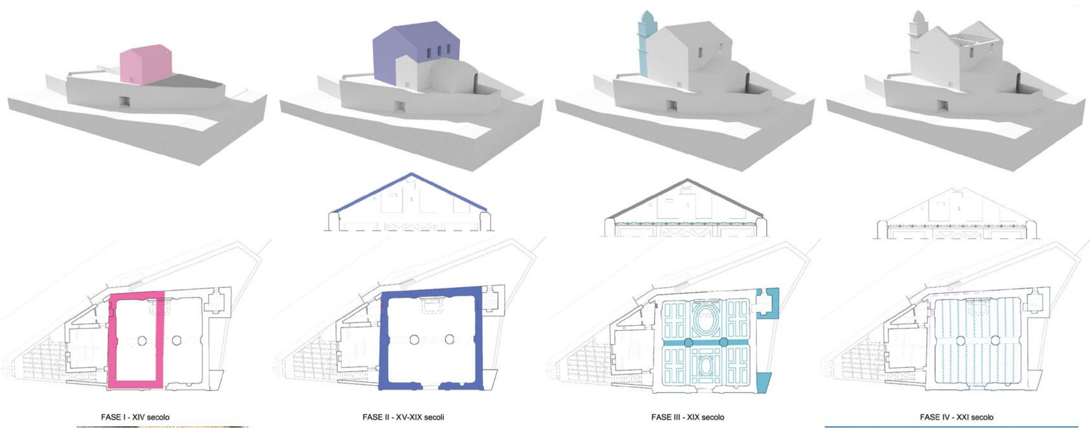


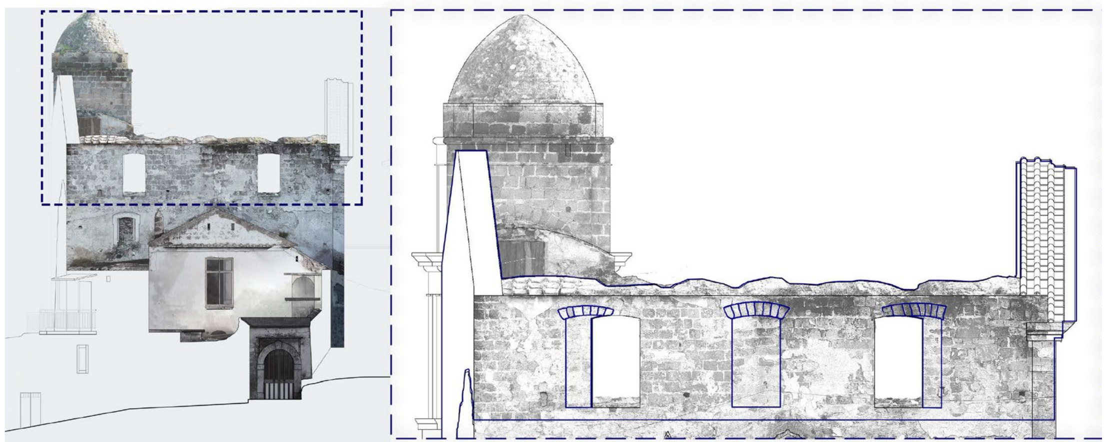
Fig. 9 Reconstructive hypotheses of the main transformations of the complex

the current openings. It was possible to identify their remains on the orthophotos made starting from the drone survey (Fig. 10);

- XIX Century: the construction works carried out during the nineteenth century are numerous and give to the Church the actual conformation. The restoration that the Church underwent during this century was due to the damages suffered after the war bombings. First, the Chapel was entirely restored and internally decorated. The central partition is added, whose construction will involve the closing of the central openings on the East and West walls and the creation of new openings, symmetrical to the remaining ones. During this period, as well, on the North wall is positioned the altar, built in polychrome marble, and in correspondence of the entrance door is created a niche that still contains the decoration in majolica depicting the Virgin and Child with the Supplicants Souls, dated 1833. Further niches, still visible, are created at the sides of the altar, on the North wall, while others, created on the East and West walls, were then closed in the course of time, so, today, only the trace is visible. It is also possible to suppose that a pulpit and a choir, both made of wood, date back to the same period. Today they no longer exist, but it is possible to see traces of them on some points of the walls. The majolica floor should, instead, date back to the year 1882, as reported on the central decoration, together with the inscription "Santa Maria delle Grazie", probably the name with which the Church was known at the time. The year 1882 could also be the year in which the restoration works, financed by the faithful, were completed. During the same century the bell tower was built, in the North-East corner, whose creation involves the partial closure of an opening on the perimeter wall to the East, still visible today.

- XX Century: with the tragic earthquake that struck the Region in 1980, the Church suffered a series of damages and was completely abandoned for years. Especially, to make the Church unfit for use, is the collapse of large portions of the roof, both in the Chapel and in the rectory. Over time, the situation has become increasingly aggravated, giving way to an advanced state of degradation. In the summer of 2019 have been put in place by the locals of the cleaning and securing, thanks to which it was possible to remove much of the rubble and infesting vegetation. What was left of the roof and the ceiling of the Chapel has been completely removed, always for the purpose of pursuing the safety of the place, in fact are visible, today, only the iron girders of the old ceiling.

Fig. 10 The openings of the west facade transformed between centuries



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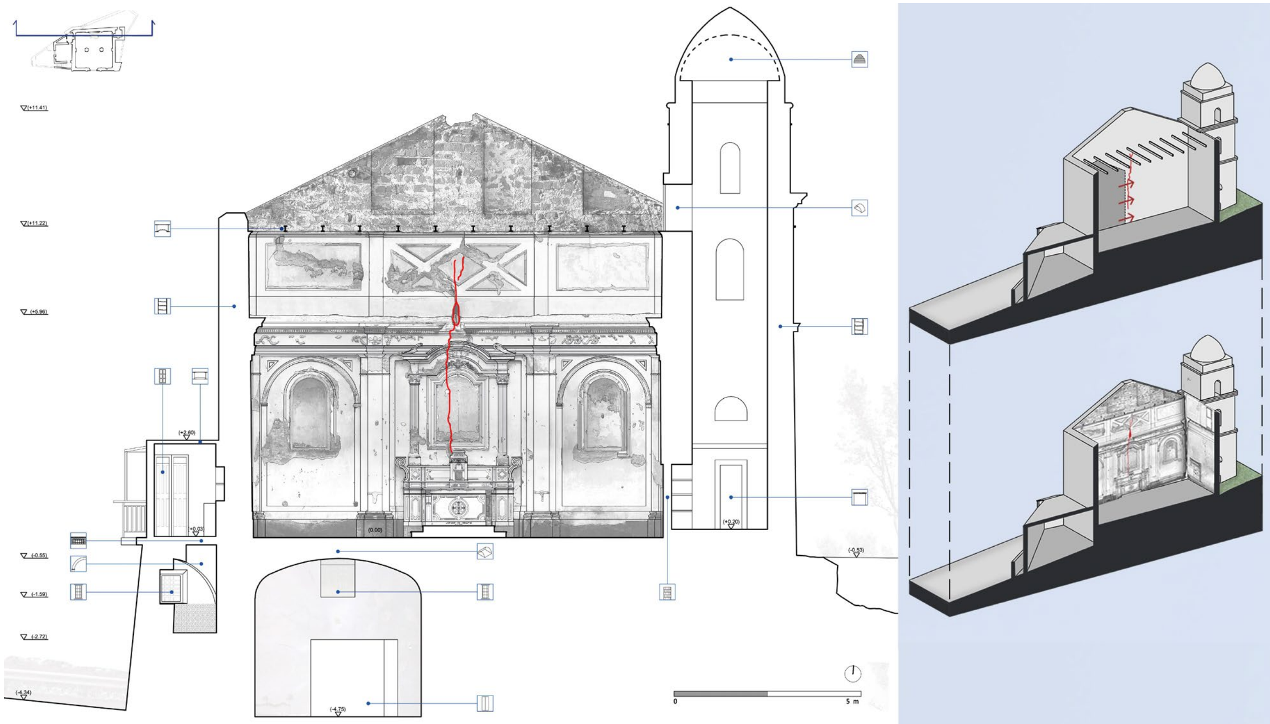

Fig. 11 Longitudinal section, crack pattern.

RESEARCH RESULTS: ANALYSIS OF THE STRUCTURE

By analysing the model of the building and the outputs produced it was possible to observe that the complex of the Church, made up of several buildings joined together, presents a very articulated cracking pattern, and this is due to the fact that the structure, which has about a thousand years of life, has undergone over time a vast series of grafts, modifications and changes. This has meant that the parts in correspondence of the additions have become the weak points of the structure and have been damaged with the occurrence of earthquakes and other phenomena. After the earthquake that struck the region in the 80s, the collapse of multiple parts of the structure has led to a very high degradation which contributed to the formation of the cracking pattern that is visible today (Fig. 11). This information is essential to undertake the analysis of structures and to assess the seismic vulnerability in both cases of "actual state" and "post-intervention state", hypothesizing solutions related to structural problems that the building presents, in order to secure it and reuse it.The modeling work is based on surveys previously carried out, using the data from the integrated survey of the complex. Based on these surveys a three-dimensional architectural model was created, using the software AutoCAD 3d, than it has been streamlined to make it suitable to be implemented, subsequently, in the finite element calculation program used for the analysis, i.e. Abaqus. Starting from the basic model, two models have been created, actually: a first model representing the actual state, and a second model representing the post-intervention state. The detailed survey of the complex has made possible achieving a comprehensive definition of the structure of the Chapel. All the information regarding the masonry thickness, the different altitudes of the part constituting the structural complex have been precisely defined. As the architectural model has been reproduced in detail in AutoCAD 3d it has been easiest the import of all the information in the Finite Element Software Abaqus where all the competent structural analysis can be carried out. The integration between these innovative technologies for the survey and the structural analysis software is of paramount importance for the definition of a structural model as more as possible detailed, which can accurately reproduce the actual behaviour of the structure under both gravity and seismic loads (Nastri & Todisco, 2022).

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CONCLUSION

The experience conducted highlights the experimental and critical investigation potentials that can be obtained through the integration of different technologies in the study of built heritage. This is especially true for those buildings, such as the case study investigated, which have passed through the centuries and therefore are the expression of an innumerable series of characters that need to be understood and interpreted to be able to preserve their resilient values.
The research has also shown that only an interdisciplinary approach and the synergy between different disciplinary skills such as design, history, restoration, science, and construction techniques, allow to reach a deep understanding of the historic building.
It was also possible to highlight how the UAV can offer excellent support for the digital acquisition campaign especially in contexts where the quality of the chromatic data is essential for understanding the architecture and the material of which it is made up. The inventory and study of these architectural artefacts are, in fact, still today based on direct investigations, photographic investigations and, if existing, on old architectural surveys – often incomplete and not very accurate that misrepresent the actual state of the goods (Versaci et al., 2020). The use of such innovative technologies for the survey can help the work of the structural engineer in the reproduction of Finite Element structural models even more accurate. It is however also true that the generation of an overproduction of data, difficult to manage and useless for the scope of the research can be a faceable risk. For this reason, it is important that, despite the growing automation of the procedures of survey and data elaboration made with increasingly performing tools and software, the architect should continue to play the main role, ensuring critical control of the entire survey process. Likewise the quality of a model and then of a survey will only be guaranteed if the outcome of the surveyor's work will configure itself as a reliable document for multiple interpretations in the future (Fallavolita & Ugolini, 2017).

NOTE

[1] The research presented here is the result of the collective work of the authors, whose relative paragraphs are reported below. Emanuela De Feo wrote paragraphs "The case study: the "Madonna del Fieno" chapel in Fisciano", "The integrated digital survey of the complex for documentation", "Research results: outputs and historical reconstruction" and "Conclusion"; Elide Nastri wrote paragraphs "Introduction" and "Research results: analysis of the structure".

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