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# Drone survey for the documentation of degraded buildings

The paper presents the results of a survey campaign carried out on the church of Santa Maria della Purità in Giugliano in Campania, a fine example of Baroque sacred architecture built on the designs of the famous architect Domenico Antonio Vaccaro. The church has been closed to the public for 27 years due to the danger of falling portions of stucco and plaster, damaged by copious water infiltration, and has lesions on the intrados of the dome. On the extrados, on the other hand, portions of the covering's majolica tiles are missing, and vegetation is present. The survey therefore aimed to document both the geometry of the building, of which a recent survey was not available, and the deteriorating conditions of the structure and cladding. Due to the unsafe conditions limiting the stay inside the church, it was decided to use expeditious data acquisition procedures. The survey of the church of Santa Maria della Purità was carried out with the integration of two instrumentations: the drone survey of the exterior, which was especially useful for documenting the extrados of the dome and the bell tower, and the terrestrial laser scanner survey for acquiring data on the interior of the church. In both cases, the latest generation of instrumentation was used, with simple usability, good accuracy and short time frames. The result is a georeferenced point cloud, which can also be visualized in the form of a 3D mesh, that can be used for the interpretation of the artifact, its geometric characteristics and its condition of degradation.

Keywords:
Small drones; Low-cost survey; Degrade documentation; Remote sensing; 3D modelling.


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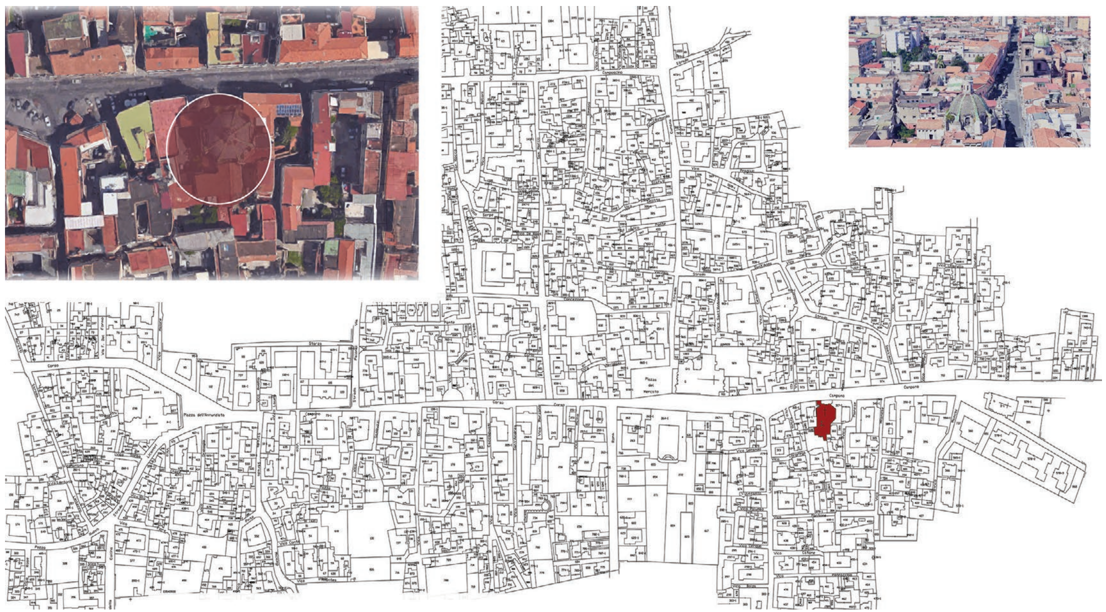
## INTRODUCTION

The use of image-based surveying methods, i.e., based on the acquisition of images to derive three-dimensional models of the surveyed area (Remondino & El-Hakim, 2006) has produced well-established and effective procedures for surveying, which use the light present in the environment to acquire photographic images, which are then processed to obtain three-dimensional data of the area under investigation. Traditional terrestrial and aerial photogrammetry has been joined in recent years by UAVs (Unmanned Aerial Vehicles). The UAVs and drones' systems are now considered suitable for many potential application fields, such as geomatics, geology, astronomy, cultural heritage, archaeology, geometric survey. The use of such instruments simplifies the documentation of architectural heritage and buildings by providing greater flexibility and a more extensive coverage (Bartolomei & Morganti, 2022).
Drones have proven very useful for nadiral or oblique image acquisition with low cost and good metric accuracy. Their portability, ease of use, and ability to reach even inaccessible areas has led to their great success, particularly in the field of documentation of the condition of buildings after catastrophic events such as earthquakes (Dominici, 2017).
A great advantage of a UAVs in a disaster situation is its flexible position that can provide both synoptic and detailed views of a complex scene, and the capacity of overcoming access limitations (Kerle, 2015). Disaster scenarios are frequently characterized by imperfect image data availability, while a rapid response is needed. In this regard it is valuable to be able to incorporate images of different types and scales into a unique model. Using UAVs is possible to acquire data to derive many kinds of useful information and visualization: georeferenced images, terrain information, digital elevation models (DEM), orthophotos or orthomosaics (Lewis, 2007). Geometric information is useful in documentation of damage detection, as openings in roofs and façades. Also, images can be photogrammetrically processed, and used for structural damage assessment. In addition, object-based image analysis can be carried out on the images to extract damage features such as cracks or holes (Fernandez Galarreta, 2015).
Alongside the studies on the survey of buildings after a disaster, other recent works focused on monitoring and detection of damage indicators related to degradation in roads, bridges, tunnels or other infrastructures. The focus of such research has been on image or laser-based 3D reconstruction of the case study, as a basis for visual or automated damage identification (Akbar, 2019). The same monitoring techniques can be applied to historic buildings to check their eventual deterioration over time, or the advance of existing deterioration processes (Sun & Wang, 2018). In any case, the choice of the most appropriate survey technique depends on many factors, such as the purpose of the survey, the cost, the characteristics of the site, its accessibility, and the level of detail required. Recent research activities also compared different surveying instruments to verify the data quality and accuracy, as well as the inherent advantages of using one technology over another in relation to the characteristics of the site (D'Agostino et al, 2022).
The case study presented here is characterized by an advanced state of degradation not due to catastrophic events but to the total absence of ordinary maintenance, which nevertheless compromised its accessibility. For this reason, we opted for an expeditious survey aimed at documenting its geometric characteristics and performing a preliminary analysis of the degradation, to solicit a desirable intervention of conservative restoration of the monument.

Fig. 1 - The position of the church of Santa Maria della Purità in the cadastral map of Giugliano in Campania (Naples).

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## THE CHURCH OF SANTA MARIA DELLA PURITÀ

The Church of Santa Maria della Purità, also known as the Church of the Purgatory Souls, is a fine example of Baroque sacred architecture. It stands in Giugliano in Campania, with its façade facing north on Corso Campano (fig. 1). The priest Fabio Sebastiano Santoro, in his text "Scola di canto fermo..." of 1715, in which he also provides news about the churches and convents of Giugliano, ascribes the origin of the church to the practice of the faithful of praying to the Virgin of Purgatory at a votive aedicule in the place where the church now stands (Santoro, 1715). At the bases of the aedicule were arranged a multitude of souls of Purgatory, hence the church's double name. This was erected thanks to donations collected from the faithful, based on a design by Domenico Antonio Vaccaro, one of the best-known architects of the Neapolitan eighteenth century, to whom is also attributed the design of the interior stucco work and the covering of the extrados of the dome. The model for the church design is the chapel of the Pio Monte della Misericordia in Naples, from which he took the octagonal plan on which the dome is grafted and the disposition of the side chapels. The foundation stone was laid in 1700, while the completion and inauguration of the church are dated to 1747 (Basile, 1800). Later, in 1765, the bell tower was erected, and the façade completed with the designs of the engineer Domenico Gaetano Barba, who also authored the historical plan that illustrates the church's spaces and the surrounding areas and is valuable evidence of the geometry of the church at the date of 1763 (fig. 2).

The analysis of the historical plan shows that even at the time of its foundation, the church was surrounded by other buildings. The geometric shape on the plan, as confirmed by the survey carried out, is not a regular octagon, but rather the intersection of two Greek crosses. The one with the larger side is in axis with the entrance and the one with the smaller side is rotated at 45 degrees to it. The dome is set on the octagonal base and without a drum. It is lightened at the impost by eight large windows that give great luminosity to the interior of the church. The extrados is punctuated by ribs that descend on the counterforts and divide the dome into eight sections, each of which is covered with majolica tiles arranged in the shape of fish scales. The scales, also found in the roofing of other churches in the area, have a particular conformation, tapering slightly upward and with a semi-circular profile at the bottom, which allows them to be placed side by side and favours their adaptation to curved surfaces (Donatone, 1993). In the church under consideration, the ribs feature an alternation of green and yellow majolica tiles covering the central and lateral parts of the ribs respectively, while the sections feature a skilful play of overlapping to create a visual pattern given by the colour contrast between black and white.

The church is in a state of deterioration caused by an absolute lack of ordinary maintenance (fig. 3), for which it was closed by order of the Fire Department in 2005 due to the danger of falling parts of stucco and plaster, and to this day access is still prohibited. Inside, cracks can be seen in the key at the intrados of the sections of the dome, due to the weakening of the masonry by copious water infiltration at the impost. It is evident that the masonry is impregnated with water in large portions, a phenomenon that combined with the presence of copious vegetation results in the crumbling and detachment of large portions of plaster and stucco, particularly during the rainy season and the subsequent drying phase of the masonry in the dry season. The cracks present on the surfaces of the sections of the dome, placed along its meridians, are probably caused by the cyclical settling of the tuff masonry, which, subject to the alternation of water infiltration and drying, is greatly affected by the physiological alternating movement of swelling and retraction. On the extrados of the dome, on the other hand, the lack of portions of majolica tiles replaced by a liner and the considerable presence of vegetation are noticeable (fig. 4). The facade also presents a high level of degradation due to the corrosive power of atmospheric agents and the smog of cars on the main street of Giugliano, resulting in the formation of moisture

Fig. 2 - Domenico Gaetano Barba, plan of Santa Maria della Purità, 1763.


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Fig. 3 - Actual conditions of the church of Santa Maria della Purità. Photography by Mario Ronca.

Fig. 4 - The extrados of the dome. Photo shooting from the drone. Survey by Mario Ronca, supervisor Manuela Piscitelli.

stains, gaps, chromatic alterations, lacks, and superficial deposits. Finally, it should be noted that below the level of the church there is a hypogeum for burials with a central plan that reproduces the space above, but it is now inaccessible for security reasons, so no inspection or survey of it could be carried out.

## THE SURVEY AND DEGRADE DOCUMENTATION

The survey of the church of Santa Maria della Purità was aimed at documenting both the geometry of the building (fig. 5), of which a recent survey was not available, and the deteriorating conditions of the structure and cladding. Given the unsafe


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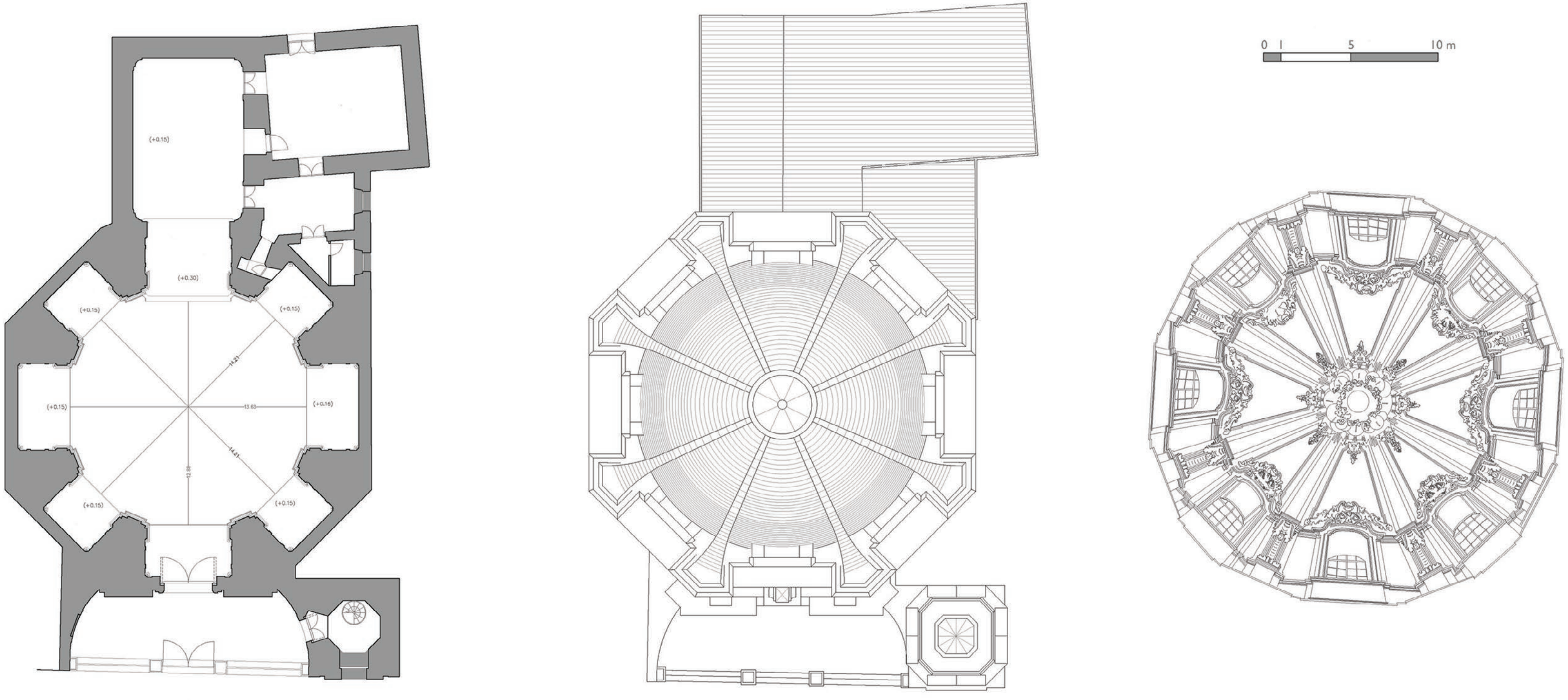


Fig. 5 - Church of Santa Maria della Purità: plan, exdtrados and intrados of the dome. Drawings by Mario Ronca, supervisor Manuela Piscitelli.

conditions limiting stay inside the church, the use of expeditious data acquisition procedures was adopted.
For the survey of the church, the integration of two instrumentations was chosen: the drone survey for the exterior, which was especially useful for documenting the extrados of the dome, the bell tower, and the façade, and the terrestrial laser scanner survey for acquiring data on the interior of the church. In both cases, the latest generation of instrumentation was used, which is easy to use, has good accuracy and short time frames. The result is a georeferenced point cloud, which can also be visualized in the form of a 3D mesh, that can be used to interpret the artifact, its geometric characteristics and its condition of degradation. The images acquired by the drone made it possible to observe in detail the majolica cladding designed by Vaccaro and to accurately determine its state of preservation.
From the operational point of view, we first worked on the acquisition of external data through the drone survey, and then on data concerning the interior of the church. Three factors most influence accuracy: the camera's calibration, the camera's network, and the ground control points with known geographic positions. The first operation was the flight planning necessary to ensure an optimal coverage, in terms of survey, of the area under investigation. It is necessary to acquire a set of digital frames of the object taken in sequence with an appropriate overlap. The fusion


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of the photographic shots through the matching points can be performed through an automatic image matching procedure, which allows extracting many matches between the different images. The overlay of the points thus identified allows the frames to be merged to obtain a three-dimensional model in the form of a point cloud, comparable to that obtained through survey techniques with active optical sensors such as laser scanners (Pierrot-Deseilligny et al, 2011). The accuracy of the model depends on the resolution of the images taken and the overlap between them, so by using a high-quality camera and a fixed-focus lens, an appreciable level of accuracy can be achieved. The accuracy of the spatial positioning of the vertices of the three-dimensional mesh depends on the focal length of the camera, the resolution of the image, and the distance of the camera from the subject to be photographed (Tumeliene et al, 2017). To capture the shots in optimal conditions, homogeneous and constant lighting is required, avoiding areas that are overexposed or covered by cast shadows. An additional advantage of these shots is that both geometric and texture information, as colours and state of preservation, can be acquired simultaneously. The data are used to produce a photorealistic three-dimensional model from which the information necessary for the thematic description of degradation can be extracted. Thus, the production of the point cloud with the metric information and the orthophotos with the photographic information takes place within the same acquisition process and using the same data source.
The survey activity consisted of acquiring the necessary data set for the photographic-based topographic survey and digital drone photogrammetry. The flight was planned through a sequence of side-by-side linear paths over the identified area. The flight technique used is the so-called low-altitude panoramic, which with respect to the speed of the drone requires frequent shots and consequently reduced exposure times. The frequency of shots was programmed every 4 seconds to achieve, at the set flight speed, an overlap between frames of about 80 percent. This overlap makes it possi-

Fig. 6 - Views of the 3D model from the drone survey. Survey by Mario Ronca, supervisor Manuela Piscitelli.


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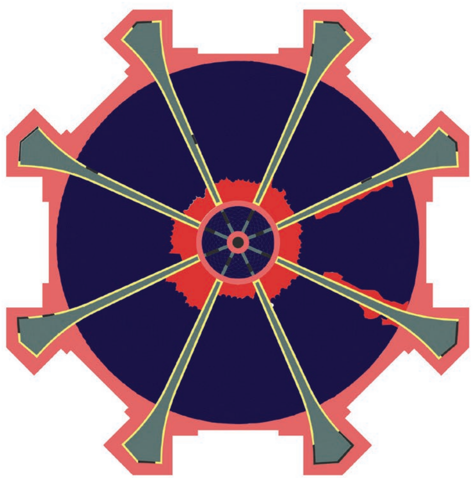
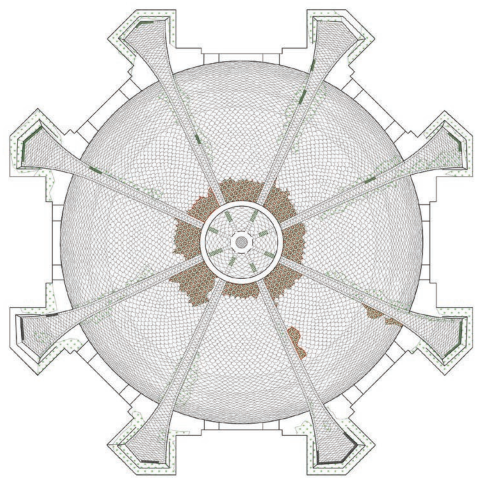
ble to identify points in common with several images, which can be used as concatenation points to obtain orthophotos and as support points for transforming the images into a three-dimensional model. The drone model used is the "Parrot ANAFI Ai," equipped with 4G connection for remote control, 48 MP image accuracy, anti-obstacle sensors, autonomous photogrammetry missions, and a robotic platform with open-source piloting application. During the flight, the drone sent images directly to Pix4D cloud for further processing. This was realized using the software Pix4Dmapper, which can automatically generate DSM, orthophoto, point cloud and mesh. During the image fusion process, the software also eliminates the perspective deformation present in the images due to the low altitude at which the shots were taken. In addition, the drone's equipment with an internal GPS makes it possible to detect the spatial position and attitude of the camera at the time of the image capture, so that the subsequently processed orthophotos are georeferenced (Luhmann et al, 2014). Alternatively, the images can be georeferenced through ground control points with known geodetic coordinates. The model obtained through the drone survey provided information about the bell tower and the exterior of the church (fig. 6). The orthophoto obtained highlighted the presence of vegetation and areas affected by degradation and gaps in the tiled covering of the dome. Processing this information, it was possible to realize thematized plans with the materials and degradation of the cupola's extrados represented according to current regulations (fig. 7). The same operation was carried out on the facades, with better results than the terrestrial laser scanner, which could not get a full coverage due to the height of the building (more than 25 metres to the extrados of the dome, and more than 34 at the top of the lantern) and the reduced space for shooting. Again, from the acquired and reprocessed data it was possible to produce thematized elevations with the degradation map (fig. 8).

Instead, for the survey of the interior of the church, the use of a terrestrial laser scanner was chosen. The output is once again a three-dimensional model in the form of a point cloud. The instrument used was the "Leica Cyclone register 360 Edition BLK," a light and handy scanner chosen for its speed of acquisition in a context such as the one described where the time spent inside the structure was limited due to the risk of falling parts of stucco and plaster. The first task was to establish the most appropriate station points to avoid the presence of visual obstacles and cover the entire area of interest. A complete mapping of the structure required the use of twelve station points, from which as many acquisitions were made (fig. 9). The appropriately georeferenced point clouds were then superimposed on each other, and through operations of decimating the cloud and removing unwanted points, a single three-dimensional model useful for the interpretation of the artifact was obtained (fig. 10). The drawings of the sections were then realized too (fig. 11). Shape registering was conducted by selecting at least three corresponding points from each point cloud. Again, the





| DEGRADO | MATERIALE | DEGRADO | MATERIALE |
| --- | --- | --- | --- |
| | Maiolica | | Gauina |
| | Maiolica | | Rappezzi di guaina bituminosa |
| | Maiolica | | Mancanza |

| MATERIALE | DEGRADO | DESCRIZIONE | CAUSE | INTERVENTI |
| --- | --- | --- | --- | --- |
| Ceramica | Mancanza | Caduta e perdita delle parti. | -Umidità; -Agenti atmosferici; -Mancanza di manutenzione; -Infiltrazioni d'acqua. | -Pulitura -Ri-Adesione -Re-integrazione; -Consolidamento; |
| Acciaio | Mancanza | Caduta e perdita delle parti. | -Agenti atmosferici; -Mancanza di manutenzione; | -Pulitura -Re-integrazione; -Consolidamento; |
| Vegetazione | Presenza Vegetazione | Presenza di individui erbacei, arbustivi o arborei | -Accumuli di umidità; -Dissesti nella tessitura muraria; -Attacco di organismi autotrofi (batteri unicellulari, alghe, licheni e piante superiori); | -Disinfestazione; -Pulitura; |
| Rappezzo di guaina bituminosa | | | -Antropico: Utilizzo improprio di materiali edili | -Rimozione -Pulitura -Re-integrazione |

Fig. 7 - Representation of the materials (on the left) and the degrade conditions (on the right) of the dome. Drawings by Mario Ronca, supervisor Manuela Piscitelli.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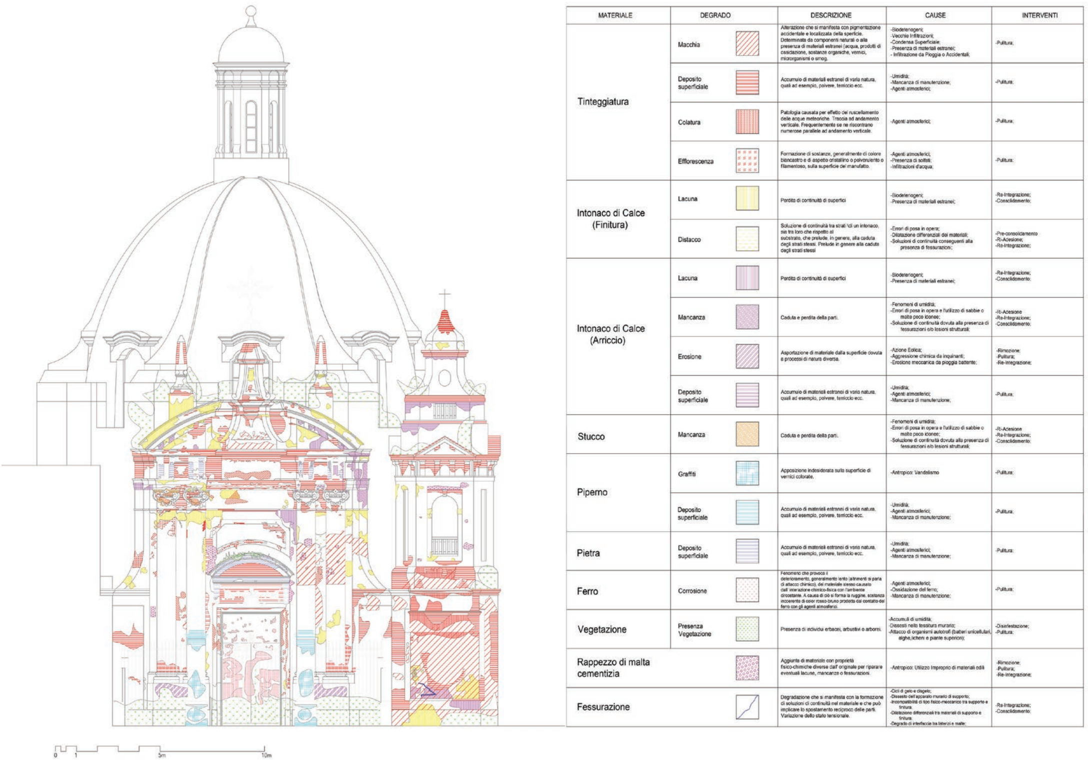
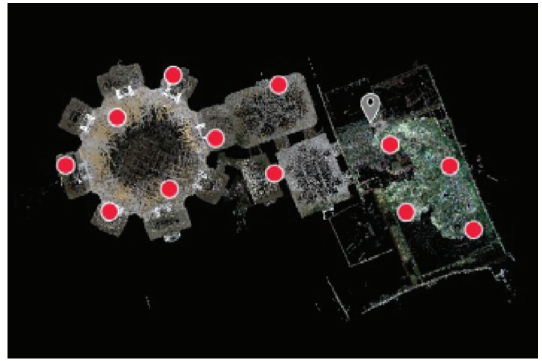



Fig. 8 - Representation of the degrade conditions of the facade. Drawings by Mario Ronca, supervisor Manuela Piscitelli.

Fig. 9 - Station points for the laser scanner acquisitions. Survey by Mario Ronca, supervisor Manuela Piscitelli.



information is not only of a metric nature, which is useful in defining the geometry of the building, but also of a photographic nature to observe the textures, colours, and state of conservation (fig. 12) and to elaborate thematic sections related to the degradation of the interior sections. In addition to scanning the interior of the church, some shots of the exterior facades were taken to facilitate the integration of data with those acquired with the survey from the drone.
Recent studies have demonstrated the possibility of integrating three-dimensional models derived from different acquisition methodologies, such as surveying by drone and terrestrial laser scanner, as their combined use overcomes the acquisition limitations of each of the two technologies used individually (Jo, 2019; Ebolese et al, 2019). The synergic characteristics of both systems can be fully utilized only after the successful registration of the laser scanning and photogrammetry data relative to a common reference frame (Habib, 2004). All acquired datasets were first processed separately. Then, they were compared and merged, to achieve a complete and accurate 3D model, using a common reference frame. A cloud-to-cloud alignment was necessary to improve or solve this registration phase. The metric comparison was performed with the CloudCompare open-source software using the Cloud-to-Cloud algorithm, which allows measurement of the metric deviation between two clouds. As in the cited studies, in the survey of the church of Santa Maria della Purità there was a discrepancy of a few centimetres in the data obtained through the two instruments used, which, however, did not affect the possibility of data integration at the scale used for the survey representation.

## CONCLUSION

The present study allowed to obtain with reduced costs and time a documentary basis to be used for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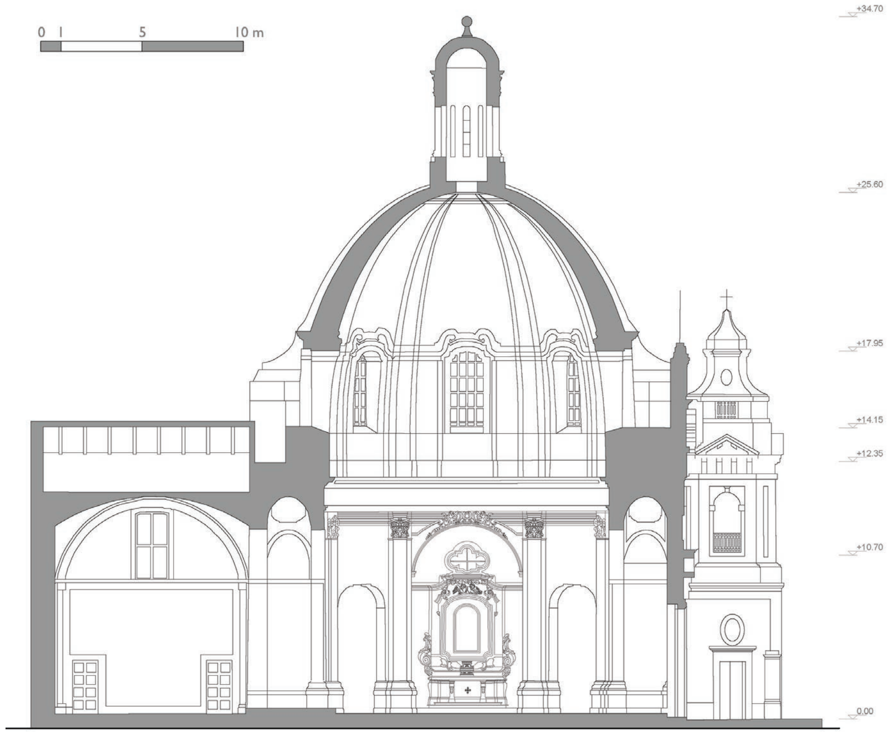
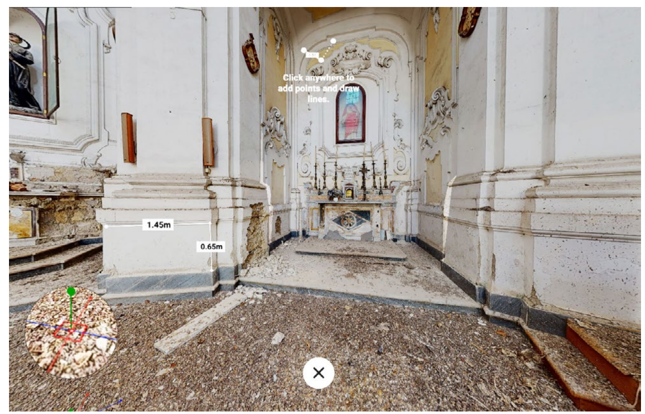



Fig. 10 - Point clouds of the interior sections of the church from the laser scanner acquisitions. Survey by Mario Ronca, supervisor Manuela Piscitelli.

Fig. 11 - Section. Drawing by Mario Ronca, supervisor Manuela Piscitelli.

Fig. 12 - Textured interactive model of the church interior, navigable and able to be queried about metric information. Survey by Mario Ronca, supervisor Manuela Piscitelli.





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the desirable future interventions to restore the building to return to the community an important testimony of the Neapolitan Baroque. The level of accuracy was considered adequate at this stage, which does not include the drafting of an executive project for the restoration of the building.
The availability of a survey at the date may also be useful for monitoring the possible progression of the level of deterioration of the building in the absence of an appropriate conservative restoration work. Indeed, recent studies have demonstrated the effectiveness of a multi-temporal approach, achieved by comparing images acquired at different times in the case of continuous monitoring of a structure, or before and after the event in the case of natural disasters (Vetrivel, 2016). Also, in the case analysed here, it will be possible to temporally monitor the building and update the thematic elaborations related to degradation, by comparing orthophotos and models related to current conditions with surveys that may be carried out in the coming years. The integration of different expeditious survey methodologies, each used in the most appropriate context, proved to obtain the maximum benefit in terms of speed of survey execution and cost containment. Digital drone photogrammetry proved to be the most appropriate expeditious technique for documenting the degradation phenomena that characterize the exterior of a building, even in a context not related to catastrophic events such as the one presented here.

## CREDITS

The survey and representation of the church of Santa Maria della Purità was carried out by Mario Ronca as part of his master's thesis in Architecture, supervisor Manuela Piscitelli, May 2022. We would like to thank engineer Antonio Iannuzzi of the Analist group for his collaboration.

## REFERENCES

Akbar, M.A., Qidwai, U., & Jahanshahi, M.R. (2019). An evaluation of image-based structural health monitoring using integrated unmanned aerial vehicle platform. *Struct. Control. Health Monit.* 2019, 26, 20.

Basile, A. (1800). *Memorie istoriche della terra di Giugliano.* Napoli: Stamperia Simoniana.

Bartolomei, C., & Morganti, C. (2022). UAV-based survey: the case of colonia Varese in Milano Marittima. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLVIII-2/W1-2022, 15–22.

D'Agostino, G., Figuera, M., Russo, G., Galizia, M., & Militello, P. M. (2022). Integrated 3D survey for the documentation and visualization of a rock-cut underground built heritage. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLVI-2/W1-2022, 167–174.

Dominici, D., Alicandro, M., & Massimi, V. (2017). Uav photogrammetry in the post-earthquake scenario: Case studies in L'Aquila. *Geomat. Nat. Hazards Risk,* 2017, 8, 87–103.

Donatone G. (1993). *La maiolica napoletana nel Rinascimento.* Roma: Gangemi Arte.

El-Hakim, S., Gonzo, L., Voltolini, F., Girardi, S., Rizzi, A., Remondino, F., & Whiting, E. (2007). Detailed 3D modeling of castles. *International Journal of Architectural Computing,* 5( 2), 199-220.

Ebolese, D., Lo Brutto, M., & Dardanelli, G. (2019). The integrated 3d survey for underground archaeological environment. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLII-2/W9, 311–317.

Fernandez Galarreta, J., Kerle, N., & Gerke, M. (2015). Uav-based urban structural damage assessment using object-based image analysis and semantic reasoning. *Nat. Hazards Earth Syst. Sci.* 2015, 15, 1087–1101.

Habib, A., Ghanma, M., & Mitishita, E. (2004). Co-registration of photogrammetric and LIDAR data: Methodology and case study. *Rev. Brasileira Cartogr.* 2004, 56, 1–13.

Jo, Y. H., & Hong, S. (2019). Three-Dimensional Digital Documentation of Cultural Heritage Site Based on the Convergence of Terrestrial Laser Scanning and Unmanned Aerial Vehicle Photogrammetry. *ISPRS International Journal of Geo-Information*, 2019, 8, 53.

Kerle, N. (2015). Disasters: Risk assessment, management, and post-disaster studies using remote sensing. In Thenkabail, P.S., Ed., *Remote Sensing of Water Resources, Disasters, and Urban Studies* (pp. 455-481). Boca Raton, USA: CRC Press.

Lewis, G. (2007). Evaluating the use of a low-cost unmanned aerial vehicle platform in acquiring digital imagery for emergency response. In Li, J., Zlatanova, S., Fabbri, A.G., Eds., *Geomatics Solutions for Disaster Management* (pp. 117-133). Berlin/Heidelberg, Germany: Springer.

Luhmann, T., Robson, S., Kyle, S., & Böhm J. (2014). *Close Range Photogrammetry: 3D Imaging Techniques* – 2nd Edition. Berlin, Germany: Walter De Gruyter Inc.

Pierrot-Deseilligny, M., De Luca, L., & Remondino, F. (2011). Automated image-based procedures for accurate artifacts 3D modeling and orthoimage generation. *Geoinformatics FCE CTU* 6, 291-299.

Santoro, F. S. (1715). *Scola di canto fermo in cui s'insegnano facilissime, e chiare regole per ben cantare, e componere, non meno utile che necessaria ad ogni ecclesiastico.* Napoli: stamperia di Novello De Bonis stampatore arcivescovale.

Sun, S., & Wang, B. (2018). Low-altitude UAV 3D modeling technology in the application of ancient buildings protection situation assessment. *Energy Procedia*, 153, 320–324.

Tumeliene E., Nareiko V., & Suziedelyte Visockiene J. (2017). Photogrammetric measurements of heritage objects. *ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci.*, IV-5/W1, 71–76.

Vetrivel, A., Duarte, D., Nex, F., Gerke, M., Kerle, N., & Vosselman, G. (2016). Potential of multi-temporal oblique airborne imagery for structural damage assessment. *ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci.*, III-3, 355–362.


DOI: https://doi.org/10.20365/disegnarecon.29.2022.7