# THE RUPESTRIAN CHURCH OF SAN PIETRO DA MORRONE (MATERA, ITALY): INSIGHTS AND PHOTOGRAMMETRIC-BASED CHARACTERISATION

***Rafael Ramírez Eudave****
Institute for Sustainability and Innovation in Structural Engineering (ISISE)
University of Minho, Portugal.

***Michele D'Amato, Giuseppe Andrisani***
Department of European and Mediterranean Cultures (DiCEM)
University of Basilicata, Italy.

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## 1. Introduction

Architectonic manifestations are vehicles for the creativity and the spirit of a culture. These assets represent documental evidence of human technical capacities, beliefs, identities and the vision that people have about themselves and the world. The city, then, represents a process of permanent construction of heritage as one of the cores for collective cohesion [1]. It is important to recognise the symbiosis between the intangible and tangible values that coexist in a cultural asset. In other words, to identify and characterise the physical consequences of the cultural assets (such as colours, geometries, spatial organisations, elements of design, etc.) is a necessary step for contextualising the object and its intangible values.

Protecting the cultural heritage is an essential activity for ensuring the continuity of a culture and its values; the presence of cultural assets is not sufficient by itself. It is necessary to adequately transmit and share their meanings and values. In other words, the social function of heritage depends on the socialisation and adequate interpretation of the material objects. The international recommendations on Historic Urban Landscapes (HULs) [2] remark the value of documenting the historical city as a step for promoting the knowledge of cultural assets. This process is important for sharing, but also for the development of scientifically supported interventions, also in the context of natural risks [3].

There are numerous examples of the use of photogrammetry for surveying cultural assets in the continuous process of its enhancement [4]. Some examples include the use of Unmanned Aerial Vehicles for facilitating data acquisition on territorial-scale surveys, such as archaeological sites [5]; other relevant experiences integrate the generation of three-dimensional models of architectonic assets in the context of territorial-scale maps [6] and even the use of unconventional sensors, such as spherical photographs [7]. Moreover, the application of the photogrammetric approach for religious

* Corresponding author: r.92@outlook.es

cultural assets has successful examples. The case of the Church of San Francisco in Betanzos (La Coruña, Spain) demonstrates the three-dimensional modelling of a complex gothic structure [8]. A remarkable example of photogrammetric survey, including wall-paintings, can be found in the work on the churches in Göreme Valley (Cappadocia, Tukey) [9] or in the works of Russo et al. [10] in which this approach was used for mapping the decay of historical façades.

In the context of a globalising world, there is an increasing interest in recognising and protecting those cultural expressions that transcend their local contexts and become representative for the whole of humankind. At an international level, the United Nations Educational, Scientific and Cultural Organisation (UNESCO) encourages the recognition of outstanding examples of cultural heritage, such as the case of the Sassi di Matera.

## 2. The «Sassi di Matera»

The city of Matera is located in the region of Basilicata, in the south of Italy (Figure 1), a region that has been permanently inhabited since the Palaeolithic period due to the convenient availability of several resources and a favourable geological environment [11]. There are two well-defined limits framing the territory of Matera. The east side is limited by a canyon (Gravina della Murgia) that divides the city from the plateau of the Murgia. The west side is limited by the channel of the Bradano river. This region represents geomorphological particularities associated to its geological past.

The area emerged from the water in the Pleistocene age [12], exposing platforms of sedimentary soils with a relatively high proportion of organic components. These deposits of calcarenite are the source of the rich variety of landforms in the region. In general terms, the upper layers of the former seabed are relatively soft, favouring significant erosion even from small currents of water, which has given rise to the formation of canyons, such as in the case of the Gravina della Murgia. This process thus exposed wide surfaces of stone that were relatively easy to work, facilitating the anthropic configuration of the territory by using the excavated spaces that had been formed (Figure 2).

This relatively soft stone, calcarenite – locally known as «tufo» (tuff), not to be confused with the homonymous material of volcanic origin in the region of Campania – is critical for explaining the development of the human settlements in the region. It is a material with elevated porosity (up to 50%) and relatively poor mechanical properties (from 1 up to 5 MPa of compressive strength) [13-15]. The composition of this material includes organic content, namely marine shells. The availability and workability of this material permitted the building tradition in the region to continue for a long period, resulting in a permanent improvement of the architectonic typologies. Most constructions were originally based on the opening of excavated habitable spaces by extracting tuff from the walls of the Gravina della Murgia. Some constructions were later complemented by using the extracted material for exterior walls, façades and even enlargements.

These architectonic dynamics configurated a very particular landscape, determining an urban organisation that also reflected the consolidation of social behaviours. For example, a remarkable characteristic of Matera is the existence of small clusters of houses ("vicinato") that shared a semi-public space which was used for collective activities, namely related to water supply, social contact and as a release from the constraining excavated spaces. Another relevant attribute is the existence of collective water reservoirs for storing rainwater. The historical city of Matera (also known as the

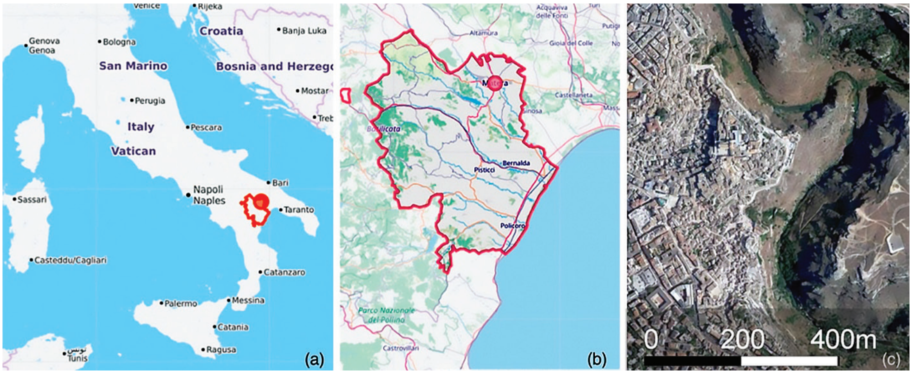


*Figure 1. Location of the Region of Basilicata in Italy. (a) Location of Matera in the Region of Basilicata and; (b) satellite view of the city and; (c) Gravina della Murgia. (source images: (a) and (b) Open Streen Maps®; (c) Google Maps®).*

*Figure 2. Sassi di Matera as seen from the west.*

Sassi di Matera) materially represents a long tradition of knowledge on sustainable social dynamics [16].

The first decades of the 20th century in Matera were characterised by sustained demographic growth that coincided with an important pastoralist crisis. The situation caused a marked degradation in living conditions that resulted in the violent interruption of the continuity of Matera's urban life after the Second World War [17]. The combination of events resulted in a substantial overcrowding of the rupestrian housing units, leading to poor sanitation and hygiene; the lack of sewage and running water seriously compromised the delicate equilibrium between the city and its resources [18]. The precarious living conditions, largely denounced by authors such as Carlo Levi, drastically impacted public policies. In May of 1952, the inhabitants of the Sassi were displaced to new neighbourhoods in the surroundings of the historic city. The Sassi, consequently, became a ghost town that suffered a continuous process of degradation.

It was not until 1986 that citizens were able to return to the historical city, amid growing interest in the city and its cultural values. Those values were internationally recognised when UNESCO declared the Sassi a World Heritage Site in 1993 [19]. More specifically, the ensemble of the Sassi di Matera was recognised as an outstanding example of continuous human appropriation of the landscape [20]. The declaration states that Matera meets three of the World Heritage criteria [21]:

*"Criterion (iii): The Sassi and the Park of the Rupestrian Churches of Matera represent an outstanding example of a rock-cut settlement, adapted perfectly to its geomorphological setting and ecosystem and exhibiting continuity over more than two millennia.*

*Criterion (iv): The town and park constitute an outstanding example of an architectural ensemble and landscape illustrating a number of significant stages in human history.*

*Criterion (v): The town and park represent an outstanding example of a traditional human settlement and land-use showing the evolution of a culture which has maintained a harmonious relationship with its natural environment over time".*

One of the consequences of the gradual return of urban life to the centre of Matera is the rediscovery of places that were subsequently abandoned and, in some cases, forgotten. The inclusion, study and rehabilitation of these constructions is a necessary step toward their successful urban regeneration. In fact, the vision of a sustainable historic city must start with the correct contextualisation of its assets, recognising in their configuration a testimony of social dynamics, and the use of available resources and technical capacities [22]. A remarkable case of a rediscovered cultural asset is the ancient church of San Pietro da Morrone.

## 3. The church of San Pietro da Morrone

The object of the case study is located in the district of Civita, the sector that corresponds to the former fortified city and is found at the intersection of two streets - Via Civita and Via San Potito. The church of San Pietro da Morrone is an example of an entirely excavated construction, a frequent typology in the old city of Matera. This building was explored in 2013 after more than four decades of abandonment [23]. The research work by Fontana and Paolicelli [24] after rediscovering the building gives an insight into more than seven centuries of history associated with the building.

The first mention of the church is in the testament of the Constable, Angelo de Berardis, dated 30$^{th}$ May 1318. It is mentioned as one of the main churches in the city. It is later mentioned as the Temple of San Pietro De Cataldis in the context of the visit of the Cardinal Michele Saraceno (1543-1544) and, as San Pietro de Morronibus in the context of the visit of Mons. Vincenzo Giustianini (1595-1596), being depicted as abandoned and degraded at that time. In 1623-24 the temple is described as the property of the Zaffari (or Cataldi) family. The existence of damage resulting from water infiltration and the need for urgent repair work is also documented.

The building is not mentioned in the list of churches of the archbishop of Acerenza and Matera, Vincenzo Lanfranchi (1667), which may indicate that the building was not being used as a place of worship at that moment. In 1701, Domenico Antonio de la Torre, archbishop of Matera [25], describes the church as profaned, deconsecrated and full of debris. He tries to buy the construction, describing it as a building in two sections. The temple is later mentioned as a cellar (1740), under the name of San Petuddo. The documents of the notary, Belisario Torricella (1774), describe a centuries-old church with the corrupted name of San Pituddo, reduced to being used as a cellar and devoted to a saint named San Pedrino in Tuscan dialect.

The cadastre of 1816 includes the property as a housing unit. By 1868 it is mentioned as the cave and church of San Potito and Petullo. The church was sold (under the concept of a house) in 1869 and was sold once again two years later. The Urban Cadastre of Matera of 1878 associates the property to the parcel number 1203 in Via Civita 1. The property was inherited in 1905 and 1937. The last testimonies are the acts of 1960, that declare the construction to be uninhabitable. The church, at that time associated to the numbers 19 and 20 of Via San Potito, was finally closed on the 5$^{th}$ June 1961 under Law 619 (1952). The corresponding act includes a schematic sketch of the layout (Figure 3).

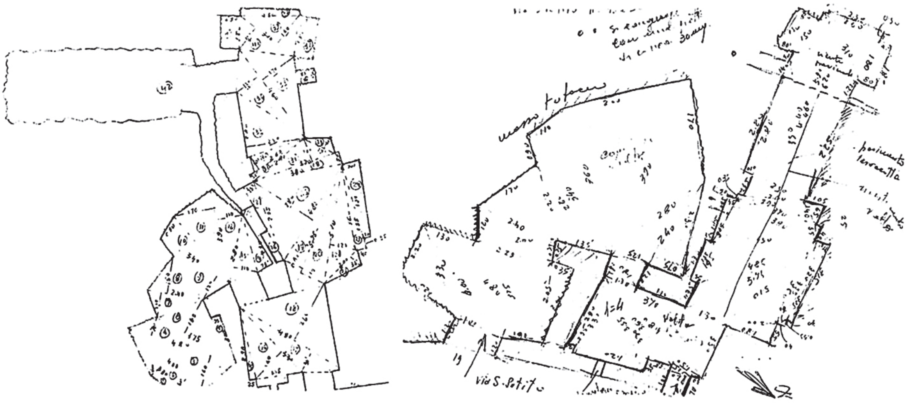


*Figure 3. Schematic sketches of the floor plan produced for the 1960 acts* (*source: adapted from* [24]).

The building has an irregular floor plan, which is typical in constructions in Matera. In fact, the workability of the rock usually constituted a basis for guiding the growth of a construction. The area of the temple is about 116 m$^2$, distributed along two main galleries. The construction is partially located under Palazzo de Vitis, a construction from the 17$^{th}$ century (Figure 4). The façade of the church presents two accesses, with no distinctive elements. There are only two small windows that may correspond to a former kitchen. At the moment of its rediscovery, there was a large amount of debris in the church, obstructing some sections of the building.

As most of the rupestrian buildings in Matera, the geometry of the church is not only irregular in the distribution of spaces: the vaults and walls are geometrically complex. Furthermore, there are several structural reinforcements and additions to the original construction, such as masonry arches, that seem to have been added to the original vaults. Interventions of reinforcement may have been carried out because of the added weight when Palazzo de Vitis was built (Figure 5). The presence of these reinforcements and other modifications demonstrates the town's dynamics in adapting and continuously reconfiguring the urban environment.

The geometric characterisation of the building was a challenging task. One of the approaches that seemed suitable to accurately characterise the church was the generation of digital three-dimensional models based on point clouds. This approach has been found especially useful when used for digitalising archaeological entities, due to the convenient cost/benefit ratio. It also facilitates the obtention of accurate measurements avoiding contact with sensitive surfaces.


*Figure 4. Oblique view showing the façade of the church (1), the access from Via San Potito (2), Via Civita (3) and the Palazzo de Vitis (4) (source: Image (Data SIO, NOAA, U. S. Navy, NGA, GEBCO) Google Earth ®).*

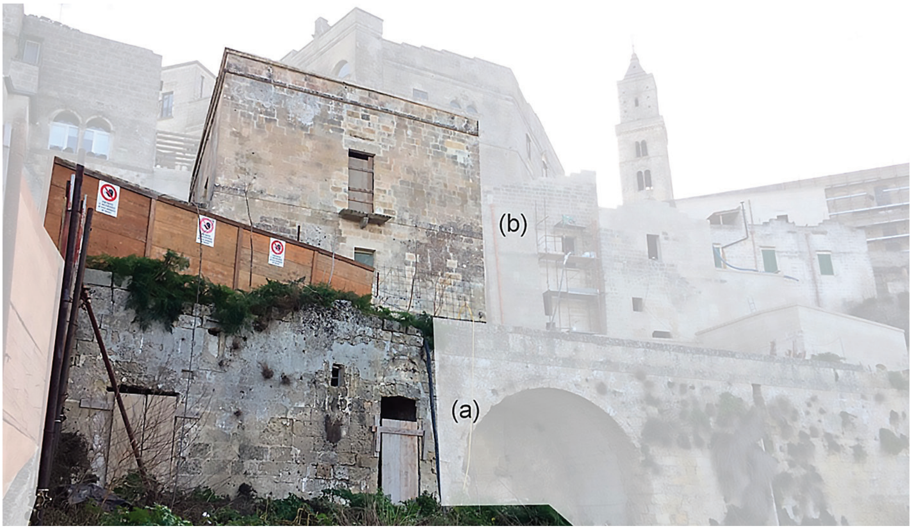


*Figure 5. Image of the façade of the church (a) and its surrounding context, including Palazzo de Vitis (b).*

## 4. The photogrammetric approach for San Pietro da Morrone: materials and methods

The use of the laser scanner is a very precise technique and has become a regular method for surveying cultural assets. However, it demands a relatively high investment in equipment and relatively complex post-processing work. On the other hand, the photogrammetric approach enables reasonably reliable results to be obtained by means of relatively simple equipment for acquiring data combined with relatively user-friendly post-processing computing. The laser approach is based on an active device that creates a cloud in which each point is associated to a precise measurement, while the photogrammetric processes are based on passive sensors (namely a photographic camera), to obtain overlapping images which permit the identification of the relative changes in some regions of the pictures in different frames.

The use of analogical photography for reconstructing three-dimensional objects has been widely used in the 20$^{th}$ century, in many cases to obtain information from aerial photographs taken from planes for use in mapping, distinguishing land features, and so on. However, it is possible to use very similar principles for reconstructing objects of a more reduced scale, such as buildings. This technique, called “close-range photogrammetry”, facilitates the obtention of sets of relative measurements that can be scaled for processing real-scale three-dimensional models [26]. Since the relative changes in different planes correspond in proportion to the distance between those planes and the camera, it is possible to calculate a relative coordinate for these distances in multiple planes, creating a three-dimensional cloud of points that maintains the proportions of the object [27]. While the laser scanner technique provides a point cloud that represents the true size and volumetry of the object, the photogrammetric approach provides a volumetry only with true proportions but is able to be scaled in order to have the real size of the object. The calibration of the cameras, however, permits to accurately scale the model based on references, depending on the specific needs of the modelling process [28].

The quality of the outcome of the photogrammetric approach depends on the data acquisition procedures as well as an adequate post-processing of the images. The basic procedure consists of taking as many photographs as needed for covering the whole surface of the object. The images must satisfy a set of conditions, such as having relevant overlapping (more than 60% is needed for close range photogrammetry), not having any substantial changes in general light conditions and maintaining the same focal length.

The redundancy on the photographs (i.e., the overlapping between contiguous images that guarantee that a certain surface appears in more than one photograph) is critical for further point matching. It is important to consider the geometry of the surveyed object in order to decide the most suitable strategy for scanning the surface during data acquisition [29]. The present case of study favoured the acquisition of images as a panorama from a central point. Depending on the scale of the survey, it is possible, and desirable, to include a series of complementary equipment for field work, such as light sources, reflectors, tripods, supports, etc. When using digital cameras for the data acquisition process, it is desirable to store the images in a minimally processed format, such as a RAW file format. Even if these files are significatively larger than the regular formats, they give better results during the matching process.

There are numerous commercial, open-source and free software options for generating point clouds from photographs. Besides, it is possible to manipulate and edit the generated point clouds by means of Computer-Assisted Design (CAD) software and numerous digital modelling platforms. It is important to consider which tools will be used to design a suitable and consistent workflow.

### *4.1. Data acquisition*

There were several limitations in acquiring data for the church of San Pietro da Morrone, namely due to the difficulties for scheduling visits to the building. Due to this situation, only one session for data acquisition was performed. The passive sensor device was a Canon® EOS Rebel T3 camera equipped with an 18-55mm lens. A tripod was used for more stable images and a 30-watt LED lamp was used during the data acquisition. However, this light source was limited to the size of the building, making it necessary to use a fixed ISO of 1600, and speeds around 1/60 s with a lens aperture of f/5.6. All the pictures were primarily stored in RAW file format with 4272 x 2848 pixels resolution and a pixel size of 5.34 x 5.34 um, giving individual files of approximately 20 MB each.

The methodology for photographing the building started with a plan of the route to scan the walls and ceilings of the construction completely. A total of fourteen stations – corresponding to a total of twelve inner spaces and two exterior stations (Figure 6) – were proposed, based on a first on-site visual inspection and the sketches of the 1960 acts.


*Figure 6. Planned route and stations. Each station corresponds to a spatial compartment of the construction.*

Each station was used as a fixed point for taking vertical sweeps of the walls and ceilings, rotating the camera just a few degrees between strips. Each photo was compared with the previous one in order to guarantee no less than 60% of overlapping. A total of 1001 pictures were necessary to cover the inner surface of the church. However, only 972 individual pictures were considered as adequate. The excluded pictures were mostly overexposed, unfocused or presented shadows or undesirable marks due to the presence of dust particles (Figure 7).

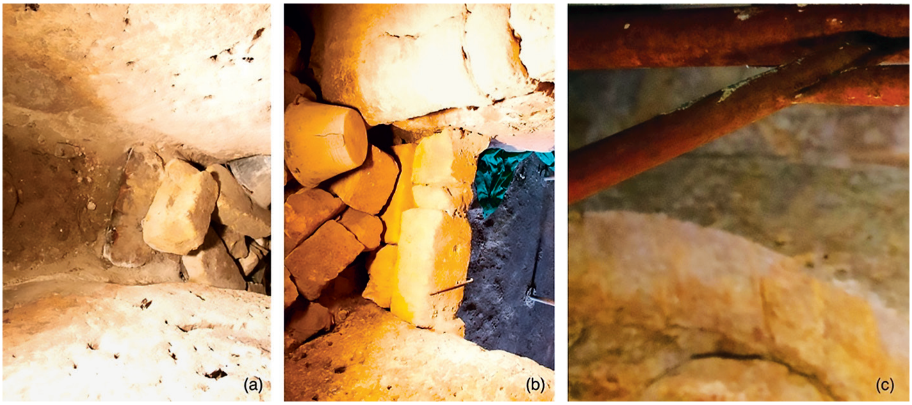


*Figure 7. Discarded photographs due to over-exposure of regions (a) and (b), or unfocused regions (c).*

### *4.2. Data processing*

In order to facilitate the processing of the pictures, they were divided into three sets (chunks) corresponding to the main divisions of the church and the stations: stations 1, 2, 3, 11 and 12 (646 images, set 1); stations 4, 5, 6 and 7 (220 images, set 2); and stations 8, 9, 10 (106 images, set 3). The location of each station is shown in Figure 6. Each set was individually processed by using a 30-day trial version of the Agisoft Photoscan software, version 1.2.5.2594. This software is easy-to-use and intuitive, making it simple, even for non-experts, to perform semi-automatic processes.

The software offers a standardised workflow, suggesting a series of default parameters. The first process consisted in the alignment of the photographs. The pair preselection was disabled. This pre-process tool is intended to identify overlapping areas based on downscaled versions of the images but may induce errors when analysing complex geometries or surfaces with no distinctive elements. A high accuracy was selected, so even some difficult overlaps were recognised through a more intense (but slower) iterative process. The default key point limit (40,000) and tie point limit (4,000) were selected.

The outcome of this first process was a low-density point cloud giving an initial orientation that was subsequently used for facilitating the creation of a dense point cloud. The initial point cloud consisted of 1,006,132 points for Set 1; 626,622 points for Set 2 and 306,942 points for Set 3, giving a total of 1,939,696 points. A medium quality was selected, with a moderate depth filtering, allowing the obtention of a dense point cloud of 131,568,523 points.

The generation of a mesh was based on the dense point cloud and was made by selecting an arbitrary surface type in the software, as well as a medium face count. The default custom face count of 200,000 was selected and interpolation was enabled to perform this process.

Texture was added to the mesh by selecting the generic mapping mode, using information from all the cameras and blending based on a mosaic model, with no colour correction. The default texture size of 4,096 was selected. This last step provides a visual three-dimensional reconstruction of the surveyed space, with rectified images in multiple planes (Figure 8). The final model was composed of a total of 6,686,337 faces and 3,344,441 vertices.

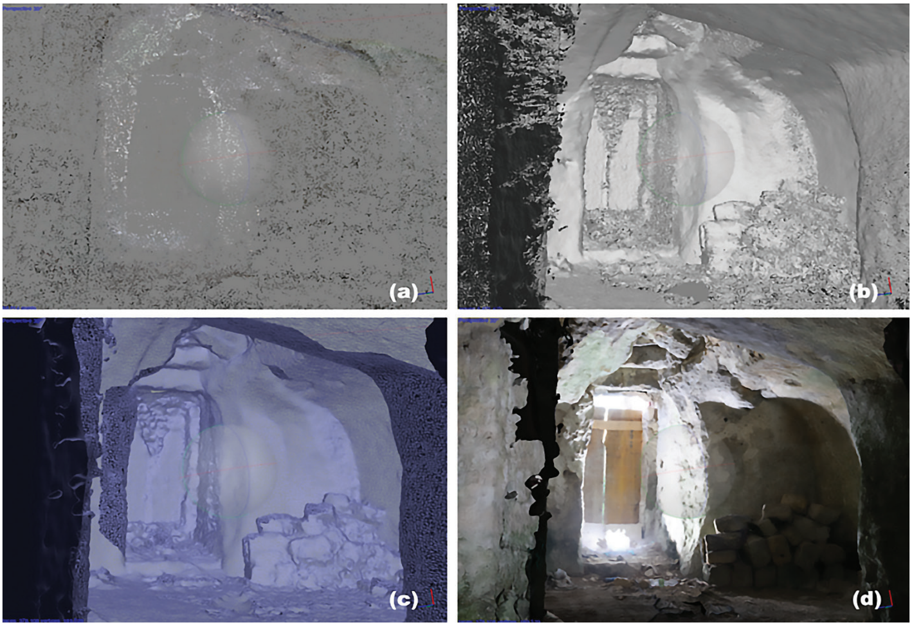


*Figure 8. Processing steps. Simple point cloud (a); dense point cloud (b); mesh (c) and surface with photographic texture (d).*

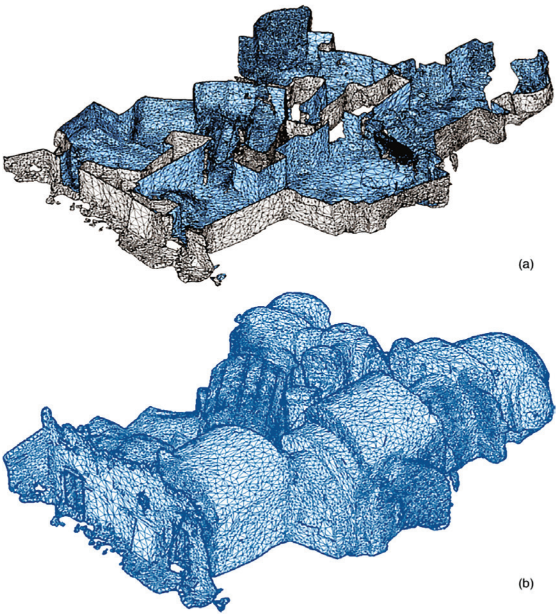


*Figure 9. Volumetric mesh of the entire church. View of a section parallel to the ground plan (a) and entire volume (b).*

The integration of the three chunks started with a manual alignment, orienting each chunk on its relative position to facilitate the automatic co-registration of the sections and the assembling of the entire model (Figure 9). Additionally, the three-dimensional axes were rotated to have a coherent spatial framework.

The final result helps gain a better understanding of the geometry of the spaces and the rock masses that divide the main galleries. This model also makes it easier to observe the difference in levels and some subtle changes on the plane of the walls that are not easily perceived on-site, namely because of the variable slope of the floor.

This comprehensive model was a valuable source for obtaining diverse profiles of the construction, which permitted us to extract multiple plan views and elevations, making it possible to measure and geometrically describe the numerous particularities of the space.

### *4.3. Results and discussion*

Several challenges emerged in managing the comprehensive model, namely due to the limited capacity of the computer. For that reason, the original mesh of more than one million longitudinal elements was reduced to a fifth of its original density. Nevertheless, no observable changes were identified, mainly because most of the eliminated vertices corresponded to almost coplanar surfaces.

Once the mesh has been obtained, it is possible to externally manage the model in numerous CAD platforms, such as Autodesk AutoCAD. Through simple volumetric operations it was possible to section the entire volumetry to obtain rectified photos for certain planes of interest. The orthophotos also permitted us to easily obtain a set of drawings to support the development of an architectonic project (Figure 10).

Even if this church does not present large frescoes or ornaments on the walls, the generation of orthophotos of longitudinal sections demonstrate the potential utility that this technique would have in the context of decorated interiors. Besides, these images are useful for documenting and analysing the pathologies found in the stones. Since the orthophotos represent the real proportions of the building, they are useful for testing project decisions and generating the corresponding documents (Figure 11). The use of an ISO of 1600 for the images intrinsically added the presence of grain as a noise source, which created minor artificial irregularities that are mostly visible in some regions of the orthophotos. The model was scaled using the Scale Bar setting and the largest measurements obtained in situ as a base. This procedure allowed verification of the right correspondence between the proportions of the model and the construction.

The automatic report provided by the software gives practical insights on the processing of the original photographs. The Ground Sampling Distance (given as ground resolution by the software) was 0.704 mm/px, covering a total area of 116 $m^2$. The total number of projections was 7,591,694 with a reprojection error of 0.725 px. The mean key point size was 5.25 px with an effective overlap of 3.30 px.

The volumetric model makes it easy to clearly distinguish some stages in the construction of the church, namely through the identification of geometrical features that vary from one space to another along the two main axes of the church. A very interesting visible element on this photogrammetric-generated plan is the existence of a very thin wall between spaces 3 and 11, which would support the hypothesis of a pre-existent communication between these spaces, thus helping to reconstruct possible configurations that the building potentially had in the past.


*Figure 10. Photogrammetric reconstruction of the ceiling (a) and floor (b) plans.*

From a structural point of view, the model was found useful for primarily identifying reinforcement elements that probably correspond to strengthening actions carried out during or after the construction of Palazzo Vitti, by projecting the perimeter of the Palazzo onto the plan of the church. In fact, it is important to note that there are several arches that would have specifically been built to bear the loads of the Palazzo (Figure 12).

The model is a valuable source for outlining an intervention project on this construction. It is possible to obtain as many sections and plans as needed, facilitating the integration of three-dimensional design processes as well. Since the surfaces are registered with the true photographic colours (as a mosaic), it is possible to perform accurate mappings of biological decay (Figure 13). It is convenient to note, however, that the photographic campaign on the building had to deal with some limitations due to the presence of debris and temporary scaffolding. These objects appear in the model and create some distortion in the real appearance of the building.

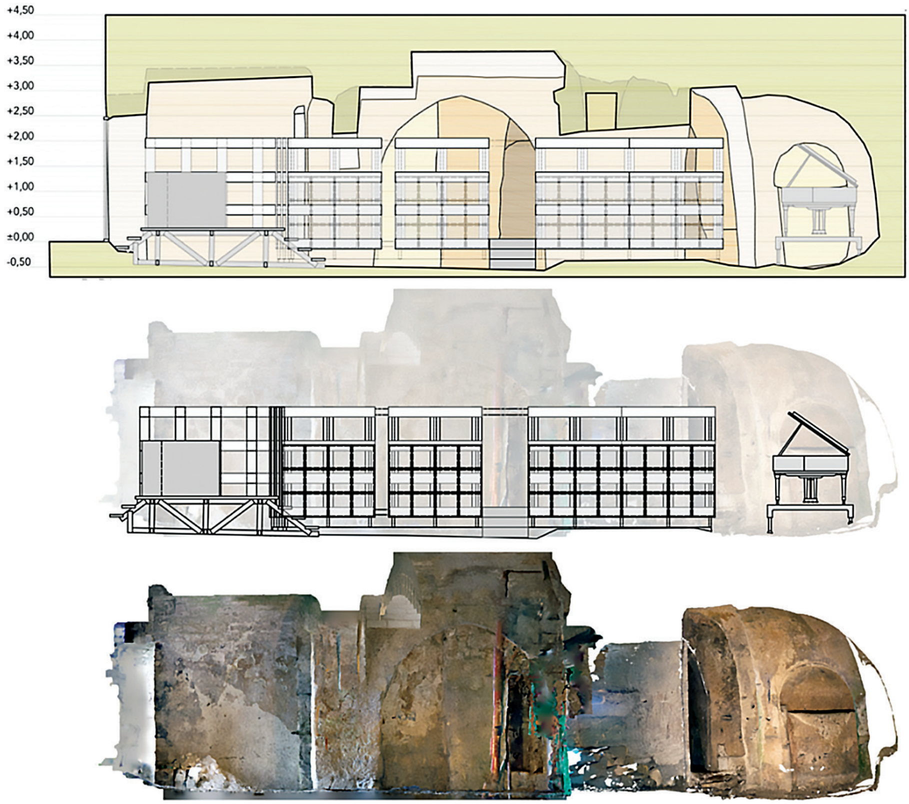


*Figure 11  Longitudinal section obtained by means of rectified photographs as a base for the design process.*

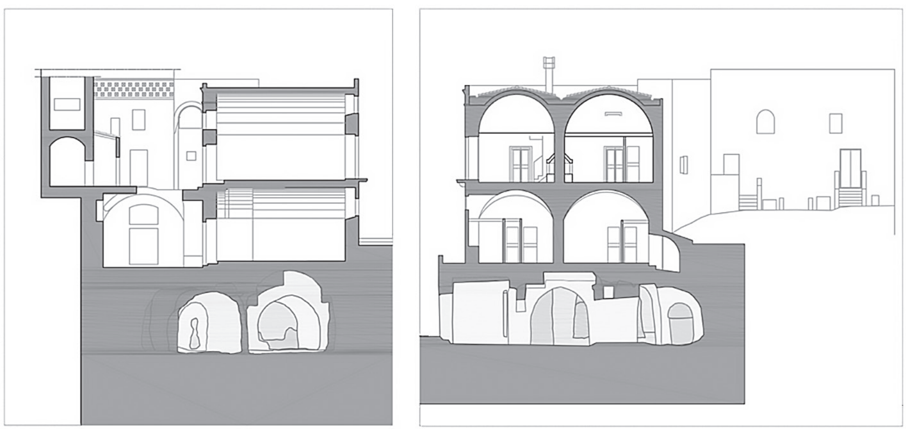

*Figure 12. Section views contextualising spatial relations between Palazzo Vitti and the Church of San Pietro da Morrone.*

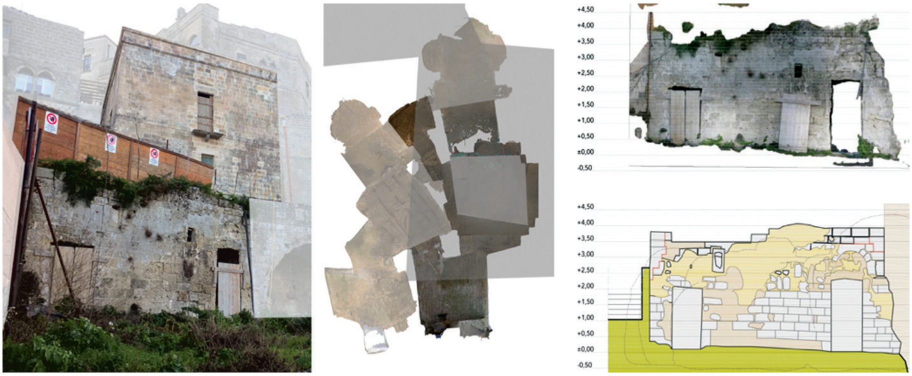

*Figure 13. Projection of the Palazzo Vitti superimposed over the plan of the church (left); identification of areas showing pathologies on the façade (right).*

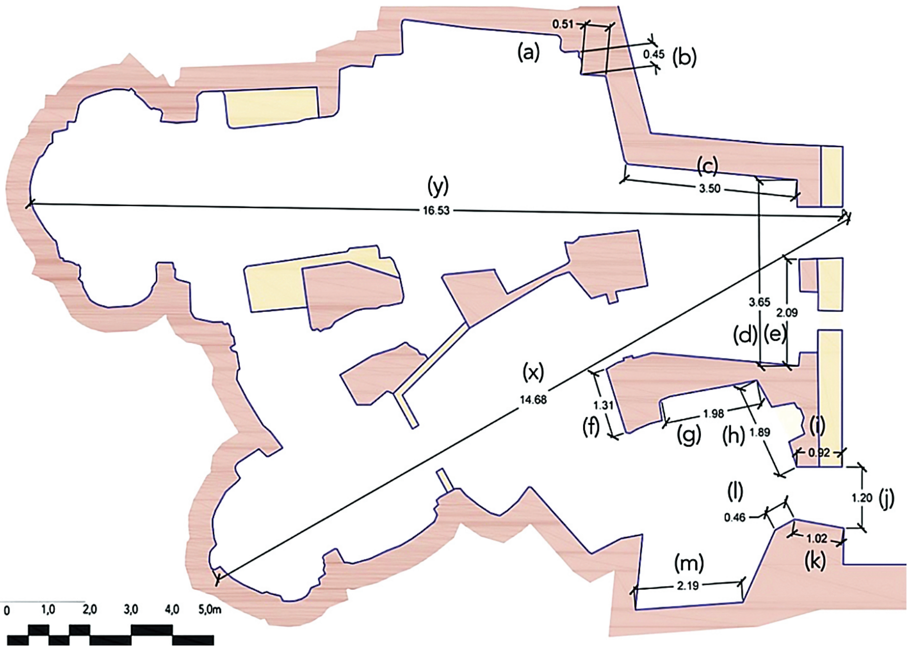


*Figure 14. Selection of measurements obtained from the three-dimensional model.*

Other relevant constraints were the difficulties associated with the illumination. It was difficult to generate adequate light conditions using a single lamp. This difficulty was reflected in regions of shadow that were not adequately modelled. These regions are specifically located in some corners and represent holes in the three-dimensional mesh. Even if the scale of these voids is almost neglectable in the context of the model, it is necessary to recognise them as a limitation for the representativeness of the model.

A set of measures obtained from the model is shown in Figure 14. When comparing measures obtained on site against the ones provided by the model, no significative variations were identified, reaffirming the suitability of the model for describing the construction.

It is convenient to note that even relatively small errors may accumulate, being especially difficult to identify on complex geometries like that of the church of San Pietro da Morrone. These errors may become relevant distortions on the geometry when the object is unproportionally long, for example. Even if it is acceptable to have a certain degree of error, it is convenient to check if error is uniformly distributed throughout the model or if there is a region or direction in which it becomes more relevant. A feasible way for verifying this randomness and distribution of errors is by comparing different distances on both the model and the building. A set of measurements performed for this purpose is summarised in Table 1. It is remarkable that the larger relative differences are found on relatively short distances. This can be explained because of the very irregular surface of the walls. The maximum absolute difference was of the order of 18cm in the longest axis of the church, of 16.53m (measured with a laser device). The differences were considered acceptable as a first-approach representation, but the model may not be suitable for designing detailed intervention projects.

*Table 1. Measurements obtained in-situ and from the model.*

| Measurement | Measurement from model (m) | Measurement with laser device (m) | Absolute difference (m) | Difference (% of laser meas.) |
|---|---|---|---|---|
| (a) | 0.51 | 0.55 | 0.04 | 7.27 |
| (b) | 0.45 | 0.44 | 0.01 | 2.27 |
| (c) | 3.5 | 3.45 | 0.05 | 1.44 |
| (d) | 3.65 | 3.65 | 0.00 | 0.00 |
| (e) | 2.09 | 2.09 | 0.00 | 0.00 |
| (f) | 1.31 | 1.31 | 0.00 | 0.00 |
| (g) | 1.98 | 2.00 | 0.02 | 1.00 |
| (h) | 1.89 | 1.93 | 0.04 | 2.07 |
| (i) | 0.92 | 0.88 | 0.04 | 4.54 |
| (j) | 1.20 | 1.19 | 0.01 | 0.84 |
| (k) | 1.02 | 0.99 | 0.03 | 3.03 |
| (l) | 0.46 | 0.50 | 0.04 | 8.00 |
| (m) | 2.19 | 2.19 | 0.00 | 0.00 |
| (x) | 14.68 | 14.52 | 0.16 | 1.10 |
| (y) | 16.53 | 16.35 | 0.18 | 1.10 |

## 5. Conclusions

The process of documenting and characterising cultural assets is not only meaningful for their conservation and protection, but also for contextualising their impact in wider entities, such as the Historical Urban Landscape. The Sassi di Matera are a remarkable example of human adaptation to a particular geological environment. Furthermore, they represent a series of strategies for optimising the use of natural resources for satisfying basic needs, such as housing. The use of excavated spaces for solving a wide variety of needs resulted in unique cultural products, such as in the case of the church of San Pietro da Morrone. The abandonment of the building and the entire city centre in the middle of the 20th century interrupted a continuum of transformation and adaptation.

The rediscovery of the church represents an opportunity for testing contemporary approaches for documenting and characterising cultural assets. A valuable technique for geometrically characterising the built environment is to generate three-dimensional models based on photographic information. These images are computationally processed in order to identify common points and reconstruct the relative position of the points in the space.

The experimental campaign accomplished the purpose of generating a three-dimensional model of the church. Several constraints were found during the experience, namely due to the limited time for conducting the in-situ survey and the lack of adequate light sources. Nevertheless, a set of more than 1,000 photographs was obtained and it was used as a base for developing a three-dimensional model.

The proportions of the model were scaled in order to obtain a reasonably accurate and descriptive representation of the volumetry of the church. This scaled model was the basis for numerous documents, such as plans, elevations and sections which gave an insight into some of the characteristics of the building and, furthermore, its potential structural relations to Palazzo de Vitis. The level of accuracy, however, may be enhanced in order to generate a more refined model for supporting executive structural projects.

This experimental program has permitted the development of a valuable model that can be further refined and enhanced. In fact, a more complete and detailed photographic campaign (including the use of on-site references and scales) would probably give more reliable results and a better idea of the real dimensions of the construction. This first experience, however, confirms the suitability of using the photogrammetric approach for documenting and increasing knowledge of the rupestrian cultural assets, thereby facilitating their conservation.

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## Biographical notes

**Rafael Ramírez Eudave** is a Ph. D. candidate at the Institute for Sustainability and Innovation in Structural Engineering of the University of Minho, Portugal. He is a member of the INFRARISK program, supported by the Portuguese Foundation for Science and Technology. He obtained his degree as an Architect in 2015 (National Autonomous

University of Mexico), and was part of the Erasmus ELARCH program, later obtaining a M. Sc. degree in Structural Analysis of Historical Constructions (University of Minho, Portugal, 2017) and in Heritage and Project (University of Basilicata, Italy, 2018). He has worked in the National Coordination of Historical Monuments of the Mexican National Institute for Anthropology and History and participated in interventions on historical constructions damaged during the 2017 earthquakes in Mexico. His current research is devoted to the assessment and mitigation of the seismic vulnerability of historical centres. He is currently a member of the Order of Engineers (Portugal).

**Michele D'Amato** is an Assistant Professor in Structural Engineering at DiCEM, Dept. of European and Mediterranean Cultures at the University of Basilicata, Matera, Italy, where he teaches "Mechanics of Materials" and "Seismic Design of Structures", on the Architecture study course. He earned his PhD in "Mathematical Methods and Models for Dynamic Systems" at the University of Basilicata in 2009. He has participated and continues to participate in different research projects focused on the seismic protection of existing and historical constructions. He is the author/co-author of several international scientific papers and has participated as a lecturer in different national and international conferences. He is a reviewer of many international scientific journals which address structural engineering.

**Giuseppe Andrisani** is an Assistant Professor in Structural Engineering at DiCEM, Dept. of European and Mediterranean Cultures of the University of Basilicata, Matera, Italy. He is an Architect at the Istituto Universitario di Architettura in Venice, Italy; a member of ICOMOS Italy (2011) and the Italian Castelli Institute. He has participated and continues to participate in different research projects focused on cultural heritage and historical constructions in Europe and Latin America. He has worked in several international groups and conferences. He is currently working on research addressing fortresses and military heritage.

**Summary**

Rupestrian cultural assets are remarkable examples of human occupation of the territory. As for any other cultural asset, the characterisation of rupestrian buildings is critical for their conservation and protection. However, there are a number of difficulties and challenges that are inherent in the physical singularities of these architectonic constructions, namely related to their geometrical irregularities. It is therefore important to use an appropriate approach to describe the geometry of these assets by overcoming some limitations that conventional measurement and surveying approaches have. The production of digital three-dimensional models is consequently a very useful and promising approach in this context. For most cultural assets and in particular geometrically complex objects, the approach is useful in reconstructing geometrical inner or exterior surfaces by means of photographic information. Photogrammetry is a technique used to acquire valuable and accurate three-dimensional information, which generates reliable models that also include integrated works, such as paintings or sculptures. The present work explores the suitability of this approach in the context of a remarkable case of rupestrian architecture, that of the church of San Pietro da Morrone. The building, located in the historical city of Matera (Italy), witnessed a series of transformations and varied uses, before it was abandoned in the

middle of the 20th century. The experimental survey of this building provides a first insight into its geometry and a point of reference for discussing the implementation of a photogrammetric approach, its advantages, limitations and possibilities.


### Riassunto

I beni culturali rupestri sono esempi notevoli di occupazione umana del territorio. Come per ogni altro bene culturale, la caratterizzazione degli edifici rupestri è fondamentale per la loro conservazione e tutela. Tuttavia vi sono una serie di difficoltà e sfide che sono inerenti alle singolarità fisiche di queste costruzioni architettoniche, in particolare legate alle loro irregolarità geometriche. È quindi importante utilizzare un approccio specifico per descrivere la geometria di questi beni superando alcune limitazioni che hanno gli approcci convenzionali di misurazione e rilevamento. La produzione di modelli tridimensionali digitali è quindi un metodo molto utile e promettente in questo contesto. Per la maggior parte dei beni culturali e in particolare per gli oggetti geometricamente complessi, l'approccio è utile per ricostruire superfici geometriche interne o esterne per mezzo di informazioni fotografiche.

La fotogrammetria è una tecnica utilizzata per acquisire informazioni tridimensionali preziose e accurate, che genera modelli affidabili che includono anche opere integrate, come dipinti o sculture. Il presente lavoro esplora l'adeguatezza di questo approccio nel contesto di un caso notevole di architettura rupestre, quello della chiesa di San Pietro da Morrone. L'edificio, situato nella storica città di Matera (Italia), ha subito una serie di trasformazioni e vari usi, prima di essere abbandonato a metà del XX secolo. Il rilievo sperimentale di questo edificio fornisce una prima visione della sua geometria e un punto di riferimento per discutere l'implementazione di un approccio fotogrammetrico, i suoi vantaggi, limiti e possibilità.