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3D DOCUMENTATION FOR ARCHAEOLOGICAL CONSERVATION: SOME CASE STUDIES IN CENTRAL SICILY

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Abstract

Artificial cavities are tangible signs of past generations' actions: a legacy that holds unique features because every wall, every vault, every recess obtained by material removing is an original and not repeatable piece. The study of these underground spaces requires a specific approach aimed at the recognition of their constructive singularities and should follow rigorous measurement procedures. In this sense, two activities, the one related to the Grotto of Saints in Enna, a space carved into the rock, showing frescoes from13th century BC and the other to the Necropolis of Realmese (9th-7th centuries BC) in Calascibetta, were conducted based on an integrated approach between traditional techniques and data capture technologies. Both sites represent an interesting field of study in terms of 3D data acquisition and investigation aimed at drawing up conservation and valorisation projects able to give back to the community these important witnesses of civilization and culture.

Keywords

Rock-cut architecture, 3D survey, documentation, conservation, valorisation, archaeological sites, Sicily

1. *Introduction*

Primitive people used caves - i.e. the underground caverns generated by spontaneous karstic, erosive or volcanic phenomena - for shelter. With the coming of the first working instruments - and the resultant possibility of moulding cavities for specific housing or rituals needs - rock structures spread. They were mostly situated along the mountains and predominantly ranged in horizontal directions, often taking shape as terraced structures in which the excavation, not restricted to the inside, also generated the modelling of rocky faces.

In Sicily, rock settlements have prehistoric origins, dating back to the pre-Hellenic cultures. Reused over the centuries, they gave rise to different types of troglodyte cave-cities, as well as to a multitude of spaces established for religious purposes, with both eremitic and urban characters: the so-called rock-hewn churches.

These structures were mostly located in the center of the island, as well as in the so-called Hyblaean area (South-Eastern Sicily). This region, which extends from the Simeto and San Leonardo plains towards that of Gela, is characterized by yellowish-white calcareous plateaus, especially compact, and has been the cradle of prehistoric civilizations that inhabited Sicily before the arrivals of Greeks around the middle of the 8th century BC (Arena, 2005). Its settlement's dynamics began in the Neolithic with the culture of Stentinello, whose population lived in caves surrounded by defensive moats. After this Sicanian population, the first Sicel period (corresponding to the Copper and the early Bronze Ages) followed. Represented by the *facies* of Castelluccio, it created necropolises consisting of artificial cave tombs carved into the rock, with a very low vaulted oven and a small anteroom later closed by boulders or by a stone slab decorated with bas-reliefs.

Between the 15th and 13th centuries BC in the Magnisi islet spread the culture of Thapsos (second Sicel period) that by now in the full Bronze Age, conceived the typical tholos tombs characterized by finely decorated manholes and very large cells. Later (13th-8th centuries BC), the Sicels of the rich Mycenaean colony of Thapsos occupied the hinterland, building the famous proto-urban village of Pantalica, so determining the homonymous culture. The last native civilization previous Hellenization was the culture of Finocchito, located further south of Pantalica, on the namesake mountain, and of which only the necropolis today remains. Later, Sicel cultures crossed a point of decline that obliged them to move inland, pushed by Greek invasions.

A special feature of the Sicilian rock civilization consists in the continuity in time of the attendance of the rock environment from prehistory to the Middle Ages, maybe also because of the particular geomorphology of the sites. In the Medieval era, in fact, there was a widespread reuse of prehistoric caves by people a lot more evolved. In this period, parallel to the establishment of cities surrounded by walls, placed on high ground and characterized by a dense network of roads, thanks to the spread of western hermetic asceticism during the 10th-12th centuries practiced by Christian monks, a different kind of urbanism born: the rocky one, indeed.

Troglodyte settlements in Sicily were also used during the Arab domination, as mentioned by 9th-century chronicles. This is the case of the Byzantine Village of Vallone Canalotto in Calascibetta (Enna), called *Hisn al-Giran*: a rock settlement with defensive features made up of not less than forty caves, which lasted from AD 535 to 827.

Following the decline of the Carolingian Empire and the degeneration of the Roman Church, many Christian monks became promoters of a spiritual revival, leading a solitary life and so settling in caves located far from the town centre. The traces of this kind of religious rock settlement can be found in many cells of anchoretic and hermit types, as well as in the monasteries, shrines and crypts widespread in Sicily.

The ascetic phenomenon can be read, however, as a reaction to the Islamic invasion, thus gaining a strong Western sense linked to the Byzantine and Norman presence in the island. However, beside to the religious reasons that led groups of monks to break away from the city, there are other political and economic ones related to a period of difficulty experienced by some medieval towns, which obliged several people, pressed by the harassment of the feudal lords in crisis, to choose rockier rather than urban lifestyles. Therefore, in addition to the monastic cells, more complex settlements can also be found: multicellular housing with specialized spaces both inside (vestibule, beddings, kitchen, closets) and outside (stables, warehouses for foodstuffs, corrals, wells, tanks, ducts, tombs, paths, walls of fortification, etc.); real rural cities opposed to urban areas. Most of these medieval settlements have reused the existing prehistoric caves, although there are examples of population thickened in new sites established in artificially dug caves.

The knowledge, conservation and valorisation of such settlements, valuable elements of Sicilian cultural heritage, often "real treasure chests where are kept some of the oldest pictorial examples (Byzantine frescoes) of the island" (ICCD, 2007-2008) remain today lacking of an adequate documentary apparatus that could lead to their full understanding and proper dissemination to a wide audience.

The very recent interest in the archaeological landscape, especially of Central Sicily and of the aforementioned Hyblaean's area, has favoured the creation of "cultural routes", record sheets, a number of publications - both scientific and popular -, aimed at improving the awareness of places which are of great importance from historical, artistic, architectural, landscaping and naturalistic point of views.

However, it appears strange, as this material still mainly comprises graphical representations made by traditional and static images that do not lend themselves to describe these multifaceted structures.

Even more, it arouses stupor the fact that the latest real catching techniques - or at least the immersive photography - have not yet been employed to interactively and virtually allow people to get part and take advantage of a so vast wealth, unfortunately unknown to most.

This study, conducted on some of these rocky evidences located in the province of Enna, intends to be a pilot project aimed at highlighting the benefits and the important role that a proper 3D documentation - today also obtainable at low cost and by easy-to-use instruments - can play in the safeguarding, enhancement and enjoyment of archaeological heritage.

2. *Metric survey and documentation of underground structures*

The metric survey and the representation of underground structures is a very complex operation because the caves are not well adapted to be brought back to elementary geometries. Over time, this has resulted in the production of a not homogenous graphic documentation. Records generally closely conditioned by author's perception and interpretation. Drawings rendered in a schematic and essential manner - many times not explanatory of the morphological characteristics of the cavities - and/or very elaborate representations - when not overly artistic and imaginative - enriched with not consistent details, often disrespectful of the true nature of the site, especially with regard to scale and proportions.

The lack of graphic codes and criteria in the drawn documentation meant that the National Cadastre of Caves of Italy, founded in 1928 with the intention to create an inventory of natural and artificial cavities, and now entrusted to the Italian Speleological Society, presents varied and differentiated records, especially in the graphics annexed to the census sheets.

In the '70s, following the decentralization of the Cadastre on a regional basis and thanks to the publishing of handbooks for underground surveying - the *Manual of Hypogeum Surveying* by the Italian Alpine Club and the Friuli Venezia Giulia Region (Bagliani, Comar, Gherbaz & Nussdorfer, 1992) and the *Teaching notebooks* by the Italian Speleological Society (Salvatici, 1981; Silvestro, 1999) - a tentative of regulation on the techniques to be adopted for the caves' survey and their re-drawing has been introduced.

A sort of graph code has been established and, while in the absence of official standards, applied. These specialised manuals, also came out so as "the neophyte can find both explanations on means and guidance systems, and clear and simple rules to follow to make the point on topographical maps, as well as the essential techniques to be used to carry out a cave's survey"(Bagliani *et al.*, 1992). They represent an important reference providing information and suggestions for the metric survey and the representation of rock sites (Fig. 1).

In addition, a few years ago the magazine *Opera Ipogea: Journal of Speleology in Artificial Cavities* born, with the aim to document and preserve the memory of ancient underground works created by man, and to understand the habits of daily life of cultures that have occurred over time.

The measurement of underground structures has generally been - and sometimes even today is - carried out by traditional and direct surveying methods, essentially the so-called "on sight survey". The problems dictated by working in cold environments, affected by high humidity and low light, often inconvenient because of the accidental nature of the soil, require that the activities should be carried out quickly.

Following the established practice, the surveying team is constituted of at least an operator and a drawer. The first is charged with the measurement of distances between key points of a polygonal network (attached to an external network that from the entrance reaches the inner parts of the cavity). The second is engaged in the representation of the planimetric and altimetric

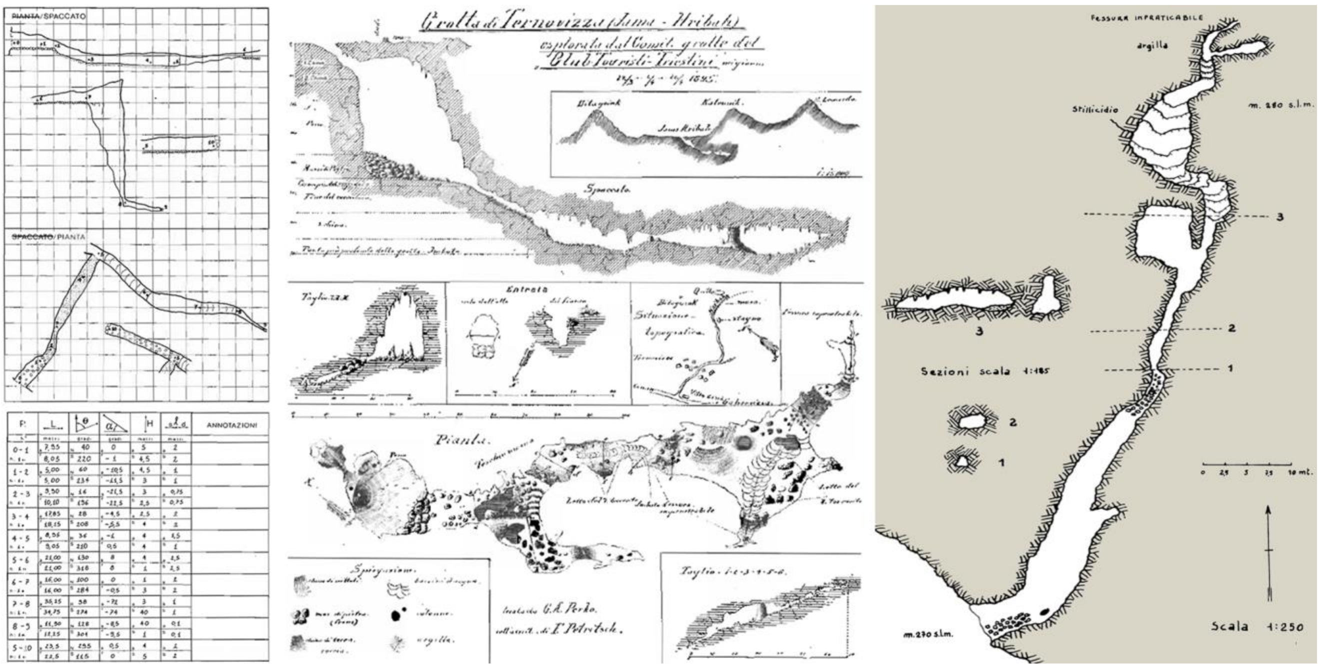

Fig. 1: The cave surveying - (from left to right) eidotypes and the field books, notes and sketches, final graphic rendering for the underground space (from the *Manual of Hypogeum Surveying* and the *Teaching notebooks* by the Italian Speleological Society).

boundaries (traced with the utmost respect of proportions) and in the cross sections of the cavity alongside benchmarks, as well as in taking notes on the material and formal aspects.

Unlike the survey of a classical building, where the most of points essential for the model's graphical drawing can be measured, for underground survey their number decreases as the most adverse and uncomfortable are the operations taken on site. In England, an alphanumeric scale constituted by a value from 1 to 7 and a letter between A and D, indicate the degree of measurements accuracy. In particular, the numerical code states the precision with which the measurements were carried out (the value 1 indicates the measurements based solely on subjective evaluation and without the use of instrumentation whereas the value 7 designates when, they are carried out with the rigorous use of total station). In addition, the alphabet ranks the details (the letter A indicates few details appreciated "by the eye" and rendered by memory, while the letter D specifies that many points were measured from a station with known coordinates).

The rendering of the data acquired, by the means of scale drawings of the cavity using flat projections, completes the activities. The cave's spatiality is "communicated" by a speleological plan, a longitudinal section (an elevation profile that follows the planimetry of the cave) and numerous cross-sections.

Although constructed in a similar way, these drawings are very different compared to the plans and elevations commonly used in architectural field. What the speleologists call a "plan" is certainly a projection obtained with a horizontal plane intersecting the object, but contrary to what happens in architecture where its level is constant, the section plane varies adapting to the height's cavity. In this type of representation, the altimetric development is not made visible while all the peculiarities of the soil are reproducible. The information on the elevation development of the cave which contains all vertical structures (pits, fireplaces, vaulted elements) are shown in a "longitudinal section"; a kind of "ideal" section where the vertical plane is properly extended, to fit in the development plan of the cave.

Cross sections complete the representation of caves. They show the inner profile obtained with vertical planes arranged at right angles to the longitudinal development; often high in number and the result of measurements now always very accurate, they are reported on a smaller scale than the plan and the longitudinal development. Iconographic signs appropriately standardized and shown in the legends attached to the tables represent the morphologic and material characteristics. It is an ordinary practice to use the colours in order to make the drawing more understandable by using, for example, the blue to indicate the hydrographic elements (such as wells and siphons) and the sepia brown for the representation of debris, boulders and sands.

Nevertheless, artificial cavities are tangible signs of the actions of past generations: a legacy that has unique features because every wall, every vault, every recess obtained "by material removing" is an original and not repeatable piece.

These particular architectures are integrated into the natural landscape manifesting themselves outside as simple holes in the rock, hiding their internal volumetric distribution. The study of these underground spaces then requires a specific approach aimed at recognition of the constructive singularities and should follow measurement procedures and rigorous investigation, never simplified. Their geometric survey is a long and laborious activity if done through traditional techniques, as these volumes are not amenable to smooth surfaces (Cardaci & Versaci, 2013).

For these reasons, a thorough knowledge and an explicit representation with appropriate levels of precision of a complex space as a cave is, requires an attentive power of observation, critical thinking and graphics capabilities, and certainly can benefit from a wise and careful use of advanced techniques such as 3D laser scanning and image-based modelling.

The use of 3D laser scanning (and photogrammetric, even with the strong limitations imposed by operating in a dark room) has profoundly altered the approach to the metric survey as it allows to redraw underground irregular spaces, fast and in an extremely accurate way.

Actually, "the underground artifact poses considerable difficulties in the metric and formal data due to the morphological nature of the articulated structure.

If on the one hand, it helps to find the key of reading of the life of a monument, on the other hand it represents the more complex problem in the geometric representation that today can be overcome thanks to the 3D technological survey's applications"(Patti, 2013).

Furthermore, new technologies allow a more effective understanding and appreciation of this hidden heritage, by means of databases easily accessible from the Internet. Thanks to the ever changing of systems increasingly performing in the digital data display, they permit the navigation in virtual environments. By now, "there is growing evidence of the active contribution that these technologies can provide in the interpretation, conservation and storage of data, as well as in the enhancement of goods through the web" (Russo, Remondino & Guidi, 2011). Nevertheless, their employment still needs to be improved and strengthened.

3. *Operational practices for documentation, digitization and preservation: the Grotto of Saints in Enna and the Necropolis of Realmese in Calascibetta.*

With the aim to document and draw up proposals geared to the safeguarding, sustainable reuse and management of this particular cultural heritage, which, in the broadest sense of the term, includes the natural environment, the architectural space, the artistic features and the archaeological artefacts discovered, two case studies were conducted. They also intend to give the opportunity to analyse innovative methodological practices related to the three-dimensional survey, the graphical representation and the techniques of conservation and valorisation of rock sites.

The activities were focused on the province of Enna, where there is abundant presence of rock settlements. However, the inadequate documentation has limited their knowledge and dissemination. This *status quo* is worsened by a reduced usability, mainly due to insufficient maintenance of the sites and their accessibility conditions.

As part of an integrated process, therefore, such experiences could play an essential role in view of the transmission of these sites to future generations but also for the benefit of the present ones.

3.1 The Grotto of Saints in Enna

The Basilian *laura* - also called *Grotto of Saints* - is a place of worship in Orthodox liturgy, certainly tied to a Basilian cenobitic form of monasticism. This space is carved into a large rock - probably collapsed from above - located in the St. Calogero district in Enna. Within the boulder, a small room, apparently dug by hand, has walls almost entirely plastered and painted with figures of saints in Byzantine style, with halos and garments richly decorated. The figures are included in boxes outlined in red. Emblematic is the image of Christ Pantocrator that appears in the center of the back wall, one of the oldest representations of the face of Christ.

The *laura* probably dates back to the 11th-12th centuries, when in Sicily, just conquered by the Normans, Basilian communities lived in difficult and inaccessible places (fig. 2).

The interruption of the cult has erased the memory of the titling of the church, now designated by the general reference to the saints painted on the walls (13th century). The location of the mural icons, respectful of rigid devotional hierarchies, suggests an attribution to St. Nicholas or St. Marguerite for the prestigious position they occupy within the priesthood. Nonetheless, we cannot exclude a titling to St. Calogero, which gives its name to the district (documents dating back to 1308 document both a church in St. Nicholas and in St. Marguerite). The circumstances of its abandonment are no known.

The church consists of a four sides-hall with a specific fan-shaped deformation to obtain a greater lighting of the inner parts. Today, it is incorporated in a building with courtyard, unfortunately in ruins maybe erected as a dependency of worship and later downgraded to a farm. There are, in fact, signs of the reuse of the cave as a stable for the presence, on the walls, of through big rings; a mill located in the right of the cave is witnessed by a settling tank with channel input and a slot in the ceiling for the screw press.

An outdoor millstone is on top of the rock; it consists of two tanks staggered in elevation, interconnected by channels. To the agricultural reuse of the cave belongs also a wooden partition recognizable for some housing holes in the floor and the ceiling, which replaced the entrance already demolished wall (Cilia, 1985; Vicari, 1993; Messina, 2001).

Re-Discovered in October 1970 by a hunter that, caught in the rain, took shelter inside and was hit by precious frescoes contained, the cave was immediately the subject of a press campaign in order to be safeguarded and valued (Emma & Spampinato, 2010). The Superintendence of Galleries of Sicily and the Archaeological Superintendence of Agrigento (at that time in charge of Enna's area) intervened and, for some

Fig. 2: The Grotto of Saints in Enna - (from top to bottom) the rock on which is carved the cave from the outside with the ruins of the farm and the cave's interior with the frescoes during survey operations.

months, it even became a place of worship. The Municipality, in order to protect the site placed a gate, which still exists, but this place was never opened to the public.

The cave entrance is m 3.66 wide, whereas at the back wall of the presbytery it width up to m 4.89. The maximum depth in the apse is m 5.24 while the ceiling has a particular trend tilted to the right (the height starts at m 2.15 and down to m 1.78) and descending from the entrance (which is m 2.28 high) till the apsidal portion (where drops down to m 1.93), from which instead goes back (up to m 2.22). The area originally occupied by the presbytery is bisected into two asymmetrical niches through a pierced rock septum that recalls to a sort of pillar.

Recently, extensive studies and the first necessary safety restoration work on the cycle of frescoes have been conducted. Based on an agreement between the Superintendence for Cultural and Environmental Heritage of Enna and the *Laboratory of Restoration of Architectural and Cultural Heritage* of Kore University of Enna, an experimentation with 3D laser scanning technology has been carried out, in order to improve its comprehension, today very limited.

Not very studied in the past, and never the objet of accurate metric surveys and diagnostics before, this monument deserves much more attention and the establishment of an extensive recovery program.

3.2 The metric survey by 3D laser scanning

3D laser scanning is an advanced technology that allows to quickly getting an extremely accurate metric survey.

The growing availability on the market of machines more and more reduced in weight and in size permits, today, thanks to an ease in the transport, their use even in tight and impervious environments as the caves.

The 3D laser scanning survey is performed through several scans made from many stations. A scan is a 3D representation of the object: a solid picture that frees up an image in which every pixel assigns a spatial position to each point "seen" by the instrument.

Only one scan cannot guarantee the detection of the whole cave; as in the photographic survey, it is necessary to take a series of images to appreciate the objet in all its details and eliminate possible hidden areas. A high number of acquisitions, while increasing the time needed for the measurements, allows, by contrast, obtaining a denser point cloud, by limiting, at the same time, the occluded parts.

The planning of survey operations is, therefore, a step of great importance that requires a particular care relating to the placement of the bases, to the predisposition of a network to support the recording, the definition of the scanning steps and the resolution of each single range scan. The final pursued result is to get a global point cloud that can totally "cover" the object of study, limiting as much as possible the shadow cones (Bertocci & Bini, 2012). A survey project needs, therefore, an appropriate choice of the stations; this allows to "register" all scans into a single absolute reference system in which the relative positions of the various stations and their orientation are known.

In the case of the Grotto of Saints, such planning has recommended to carry about fifty scans (both external and internal ones) and to place a hundred markers (reference spheres and checkerboard targets). A number greater than necessary, because of the problematics related to the alignment (references not read from the instrument due to an excessive inclination or too distant) and of the need to contain the error within a tolerance of about one centimeter.

The acquisitions made by a very small distance, never more than a few meters, allowed high density of measuring points (average distance between the points acquired between 5 and 30 millimeters) and a very low working time.

The model thus produced - the so-called "point cloud" - is an extensive digital archive that can be investigated as a function of the possible avenues of the research. It allows, for example, virtual analyses of the detected object in terms of volumes, sizes and/or centers of gravity determinations as well as to check the status of conservation of the property and setting the appropriate restoration and consolidation intervention.

The point cloud also offers an undeniable simplicity in the development of orthographic projections of irregular surfaces. From it the necessary information for the rendering of plans, elevations and cross-sections, horizontal and/or vertical profiles, axonometric and perspective views, and also tomographic projections, particularly useful in the reading of the buildings (i.e. the thickness variation of the masonry textures at different altitudes with an indication on the shape and the openings placement), can be obtained.

The geometrisation that usually applies in the graphical representation of structures that, in fact, have no or almost straight walls or stringent symmetries and that characterize the historic buildings, is often the result of instrumentations which are inadequate to the complexity of the goods and of praxis dictated by the need to "speed up" the measurement's activities. The detection of the irregularities permitted by the laser scanner and the consequent greater flexibility both in the bi and three-dimension representation is therefore not a marginal element but a trait that needs to be seized and enhanced (fig. 3).

The acquisition and digitization of 3D data by laser scanning are the first stage of processing to which follows the 3D modeling for the creation of virtual textured and navigable artefacts: models that can provide a very detailed and realistic description of the object and more containing accurate information on the geometry, materials and degradation phenomena.

The scanning product is made from raw point cloud, which, if properly treated, describes the object through a discontinuous model in which the perception of the real object is greater as denser is the cloud. The same radiometric information, besides being affected by the length of survey and the impossibility of regulating light and exposure, is heavily penalized by its re-projection only on the acquired points, so leaving some spaces of "uncertainty" (colored pixels next to other blacks).

The next phase, the so-called 3D modeling, starts with the transformation of the point cloud into a discrete - or continuous - surface through the generation of meshes, fragmented surfaces consisting of triangular polygons whose vertices are all the points making up the cloud.

The attained model is a polygonal solid which will be subjected to further automatic procedures of cleaning and, therefore, to a subsequent aging in the recording - through an "iterative closest point" algorithm (ICP) that aligns each range scan by reason of the shape of its surfaces and not only on the basis of the targets - and to the union of the meshes into a single object.

A good practice for obtaining polygonal models faithful and, at the same time, optimized for an easy handling, is to use decimation algorithms that preserve the surfaces' curvature values. Taking care of setting the point cancellation only where the surface has a greater regularity and can then be approximated to regular geometries, the mesh will be "lighter" only in the parts with values of low or zero curvature (smooth parts or flat) and very dense in zones with considerable curvature values (parts with accented details).

The polygonal model, now united, passes a final editing stage for the correction of errors that occurred during the merge process, closing the gap

Fig. 3: The Grotto of Saints in Enna - 3D laser scanning, orthographic projections of the point cloud. The planimetry and the floor plan of the cave (above), the longitudinal section (center), the isometric view and details of the interior (bottom).

and discontinuities; it is then optimized by reducing the total number of triangles to a specified value, mapped by textures obtained from separate high-resolution colour digital cameras and subjected to the final rendering.

In this case study, the use of photographic images has been addressed not to obtain a virtual model but to create a single HDR image with high resolution, true colours and high details.

The importance of the frescoes has indeed requested to pay special attention to the concerned part of the *hypogeum*, where the lights and the camera equipment were positioned (fig. 4).

The observations made on this interesting rock site have been directed to the understanding of its distinctive volumetric morphology, the identification of historical events that have marked the transformations and changes of use over time, to understand the possible correlation to the causes that have led to the current state of deterioration and instability. Such poor condition

Fig. 4: The Grotto of Saints in Enna - the frescoes. The 3D texture made by photogrammetric techniques (above), the model from 3D laser scanning survey (center), HDR panoramic image made by techniques of photo-stitching (bottom).

makes undelayable the establishment of a conservation programme of pictorial apparatus, natural stone elements and additions anthropic integrations (fig. 5).

The operational choices to achieve, however, must be framed not only in the context of architectural restoration but also in the culture of the preservation and valorisation of the cultural landscape.

Therefore, operational interventions must be addressed to both the conservation of the architectural object and the maintenance and strengthening of the relationship with its natural environment to give back to the community this important witness of local civilization and culture.

3.3 Conservative and reuse approaches

The Grotto of Saints is a valuable good, inextricably linked to the surrounding landscape and the natural setting. As already mentioned, this specific feature must absolutely be considered in the interventions to be taken, in lodge to assure its proper continuity in the time.

Above all, the monument's conservation proposals should proceed towards the elimination of degradation phenomena mostly related to water that, due to some fractures and joints in the stone surfaces and to chemical degradation of rock caused by rising capillarity, is constantly attacking frescoed internal surfaces.

The reason of this disease is probably also due to the path of rainwater along the gutters and inside the tanks and canals that were part of the old millstone surrounding the cave but this circumstance still needs to be definitively proved by further thermographic and ultrasonic tests that will be taken in the near future.

Far from thinking that it will give decisive and definitive solutions to the problems that for centuries beset the monument, the restoration project will, in any case, be based on a methodology established by the experience, taking the utmost care, tested techniques and materials.

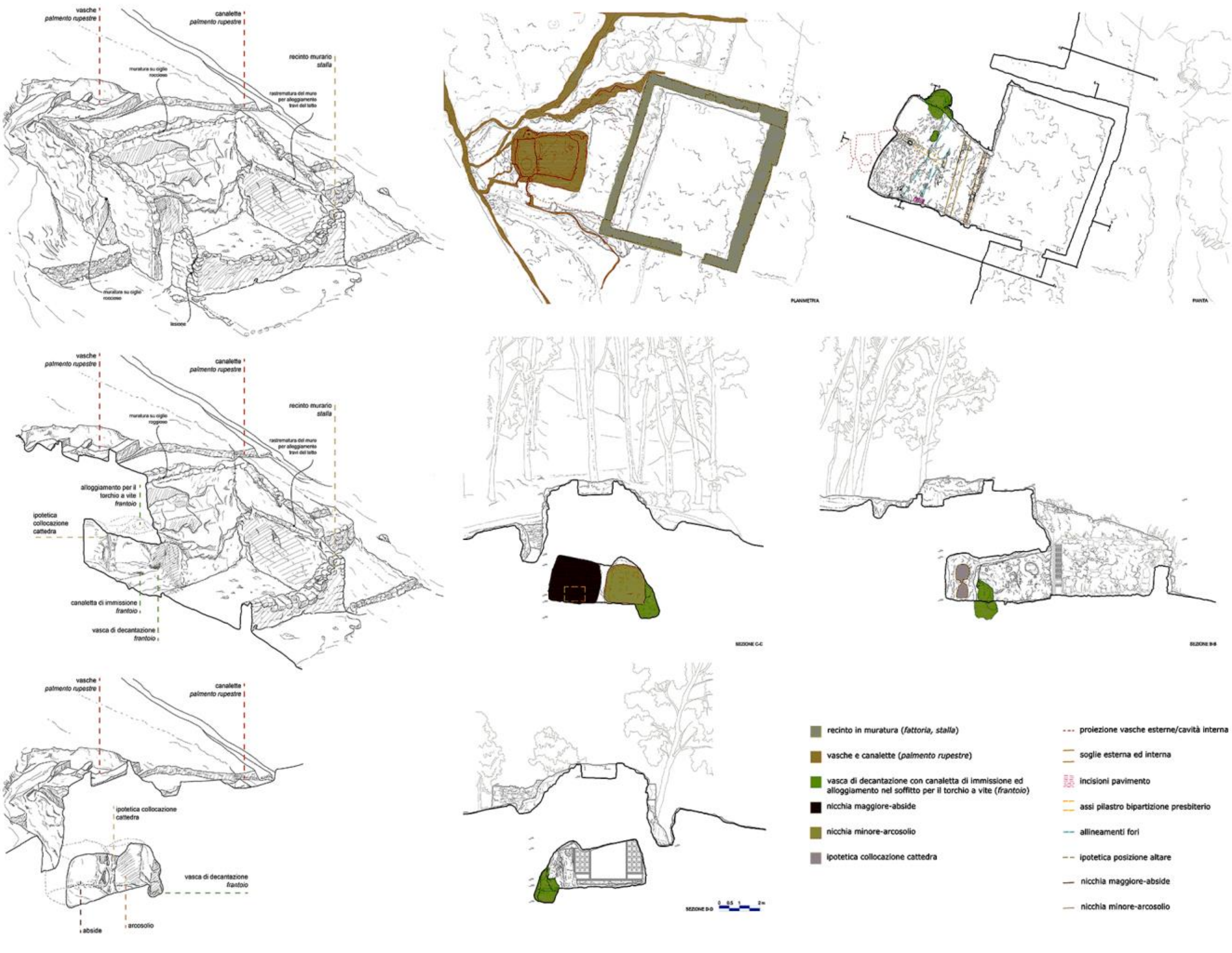

Fig. 5: The Grotto of Saints in Enna - stratigraphic analysis on 2D and 3D drawings.

It will be targeted not to alter the chemical, physical and environmental conditions reached over time.

The project should moreover focus on the possibility of building or not a new canopy in front of the entrance. Following one of these two opposing attitudes means to delve deeper into the controversial problem of the ruins' protection, restoration and reintegration. A question, which is entirely part of a wider theoretical debate on conservation and new design (Varagnoli, 2003) as well as "about the meaning of the built heritage for society, the choices about what is to be conserved, the interpretation of the past and the effect of conservation on creativity" (Loew, 1993).

The choice should be guided by the need to build a physical and material protection of both the architectural (the external fence) and archaeological-natural structures (the cave-Byzantine *laura*). It should also move from the understanding of the whole framework in which the new structure would be inserted. If, in fact, the reuse of enclosure's space would require the construction of a new roof, modern semantics should not necessarily collide with the expressiveness of both the ancient structure and the landscape.

There is today a vast literature about the language to assign to the new covering structures for the protection of archaeological sites. Such structures, for example, are designed with the intent to recall the existing system or its forms in the will to restore the old volumes. Therefore, the design of a new roof for the Grotto of Saints must be studied with the appropriate rigor and balance between the reasons of conservation and those of the reuse.

As already mentioned, today the cave is closed by a metallic gate, not tightly placed against the opening. Made up of large windows, while allowing seeing the images of the Saints from outside, it exposes them to the action of atmospheric agents (wind, water, solar radiation, temperature changes). The realization of a - sustainable and light - wood awning, which will rest on the still existing - while to be consolidated - walls of the old building, would facilitate the preservation of frescoes and their observation.

At the same time, the project would consider the need for their constant monitoring and remote fruition, by means of the web. In this sense, a second action - more consistent and constrained to the presence of electrical energy today lacking - is connected to the implementation of a continuous monitoring system (in terms of humidity and temperature) of the internal microclimate of the cave. In addition, the provision of a camera system with adjustable optical zoom, would allow discovering the interior of the cave interactively by a screen placed at distant places, such as in the headquarters of the Regional Interdisciplinary Museum.

It is finally necessary to reflect on the opportunity to re-assign this place to the religious cult, using it as a votive altar or as a small country chapel, even through the reorganization of the outer space as a small nave. An alternative might be that of its reuse as small reading room, or a meeting place for prayer groups, by integrating the grotto both in a circuit of the most famous Basilian churches in Sicily (Filangeri, 1979) and in that of the rock structures on the island, as numerous as almost unknown.

3.4 The Realmese Necropolis in Calascibetta

This second experimentation on the necropolis of Cozzo San Giuseppe, located in the district of Realmese in Calascibetta (Enna, Italy), offers a new methodological approach to the knowledge for the protection and valorization, based along the integration of modern technology with traditional practices, highlighting the features and possibilities of extension to other similar cases.

This place is among the most fascinating of Central Sicily and, alas, one of the less studied. Originated in the historic era (mid-9th century BC - first half of the 7th century BC) to perform interment functions, it was also used during the archaic age (mid-7th century - second quarter 6th century BC) (Giannitrapani, 2012).

Over the centuries, it has undergone changes that led to the reuse with housing functions of some of the burials and, therefore, to their modification in response to the new requirements. Nevertheless, the site, although inhabited during the Byzantine period, did not reach the size of a real urban complex and globally maintained its cemetery conformation.

Luigi Bernabò Brea, then Superintendent of Antiquities for Eastern Sicily, whose jurisdiction extended to the province of Enna, first excavated it between 1949 and 1950. Bernabò Brea visited the site in 1944, during a general survey of the entire province. Yet, only in the summer of 1949, he had the possibility to begin exploration of a first group of graves. Excavations resumed the following summer, but the Superintendence responsibilities inherent to a vast territory, made impossible any further continuation of the research (fig. 6).

Since the start of the investigations, the issue of the identification of individual graves was raised, requiring, then, a classification to which refer in the excavation journal and for the cataloguing of grave goods recovered.

Therefore, the necropolis was divided into areas marked with letters from A to H and, within each of them, the burials were progressively numbered.

At the end of the exploration, the total number of the graves turned out to be 288, plus some others whose excavation was just barely initiated and only a few reduced to uncertain traces.

The tombs are shaped artificial caves (*a grotticella*) directly opened in the rock through a small breach. None is preceded by a vestibule or an antechamber, nor by a real *dromos*. In general, they are little extended: between the smallest is the F16, which size is equal to m 1.30 x 0.82 x 0.66, while one of the greatest - the E13 - measures m 2.5 x 1.8 x 2.00. There is a prevalence of rounded shape graves (approximately 165); rare are those perfectly circular or semi-circular (about 20). There are also 50 chamber tombs, having the shape of a rectangle, and some hybrid forms: rectangular with rounded corners and sides more or less markedly concave. The most popular are still the oven graves, with circular plan and vaulted (Bernabò Brea, 1982).

3.5 The integration of the data capture technologies for the digitization and the comprehension

Survey activities have been executed in large scale on the complexity of the rock face and, in detail, on a series of burials chosen according to their typology, approachability and internal dimensions.

The integration of different surveying instrumentations and methodological practices has allowed, on the one hand to investigate through three-dimensional digital objets, the complexity of the necropolis and on the other

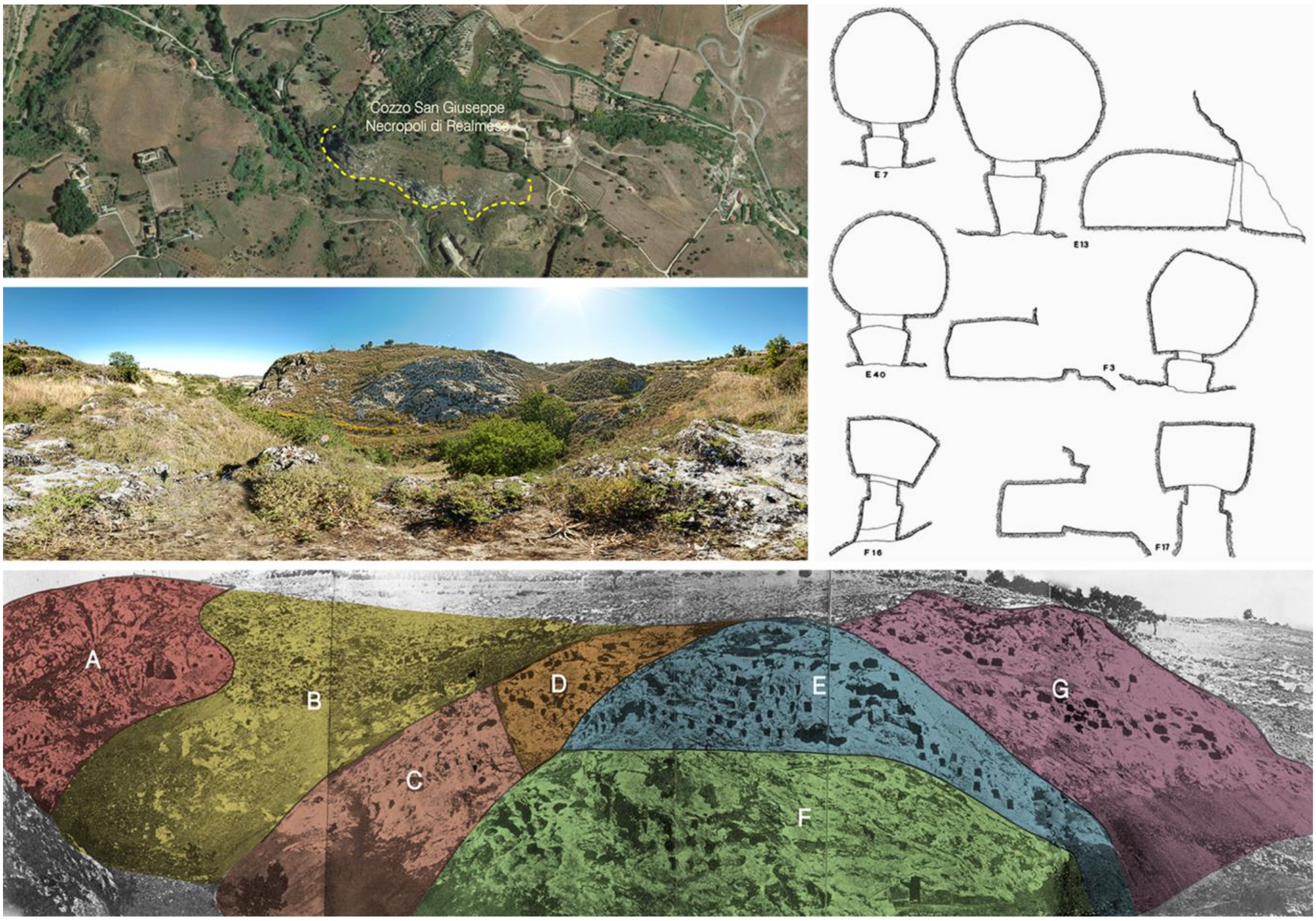

Fig. 6: The Necropolis of Realmese in Calascibetta - the promontory with the caves of the necropolis, the sectors identified in the notes of excavations carried out by Bernabò Brea and the re-drawing of some caves.

hand, to compare the effectiveness in relation to different factors (the degree of reduction of measurement error, the time of survey and data processing, the difficulty of environments access, the instrumental range).

An experiment aimed at the survey of the entire rocky face in which the necropolis develops, was carried out based on the image-based 3D reconstruction. This technique allows realizing a three-dimensional model of the object detected using photographs appropriately taken and the application of suitable photo-modeling software.

To generate a first general model related to the whole necropolis, located on a slope rather wide, stretching for more than 300 meters, special attention was paid in defining the paths to follow for acquisitions cameras.

To obtain images of the entire extent of the site, four paths were so created. The first two were located in the opposite side of the valley, along two paths - almost parallel to each other - respectively upstream and downstream of the rise, the third ran along the path downstream, near the necropolis, while the fourth was identified in a small alleyway to the east of the necropolis near the nearby quarry.

The photographic campaign, conducted with a full frame camera whose large sensor has a reduced noise, required the use of a sturdy tripod for the shooting aperture priority mode, with values chosen between F16 and F22 for a wide depth of field, and a very long time of shutter opening; about 300 photographs were taken by using several wide-angle lenses.

Developed from raw .tif files, pictures were processed using a software based on the “structure from motion” principle (SfM). Born from the convergence of different disciplines - the Computer Vision, which aims at the automatic generation of 3D models, and the photogrammetry which objective is the measurable documentation of the object - this technique enables to get an automatic 3D reproduction from pictures of objects, archaeological sites and whole urban districts with a minimal economic investment.

The photogrammetric technique requires that each frame should be properly oriented and placed in a single system of reference, and this is conceivable if, for each pair of images taken from two different points of view, there are at least five homologous points.

In fact, by identifying in both photos, common and unequivocally recognizable points, it is possible to determine the geometry of the socket (the position and the orientation of the camera at the click) to then calculate, through the principle of collinearity, the spatial coordinates of collimated points (figg. 7 and 8).

The collimation of the homologous points - a long and difficult operation through traditional systems -, is automatic thanks to the image-based 3D reconstruction software such as that here employed. By using a high number of photographs - even uncalibrated but with a high overlap -, it allows the recognition and the automatic extraction of matching features and the restitution of a complete and geo-referenced point cloud.

The subsequent conversion into a model of about 300.000 polygons, high-resolution photographic mapped, has resulted in a loyal and highly realistic model of the archaeological site.

The same technique was applied for the survey of the tomb identified with the code F20 located at the base of the F field of the necropolis, chosen for its large size, its particular morphology and the ease of access.

As part of this experimentation, it was also possible to compare the acquired data with a digital model obtained by the development of a 3D laser scanner campaign, which concerned six other small tombs, as well as the same F20. In some other cases, the only indoor of the caves was surveyed, due to problems related to the safe positioning of the instruments on the steep slope.

Concerning tomb F20, set at the end of a small path that widens near the entrance, it was possible to analyse in high detail, the relationship with the external front (Fig. 9).

The point clouds obtained by 3D laser scanning survey allowed to capturing metric and physical reality of architectural objects, enabling the creation of extremely precise orthographic projections. Following a subsequent data processing, a polygonal model of the burial absolutely true to reality and useful to the study of its complex morphology and material-constructive characteristics - was produced.

A top priority for the representation and communication of historical architecture, extremely hard in the case of underground cavities, is its full understanding. It is impossible to draw something that has not been previously examined by the brain, by reasoning, by a careful observation of reality.

Nothing can be rationally possessed and clearly expressed if has not first been experienced,

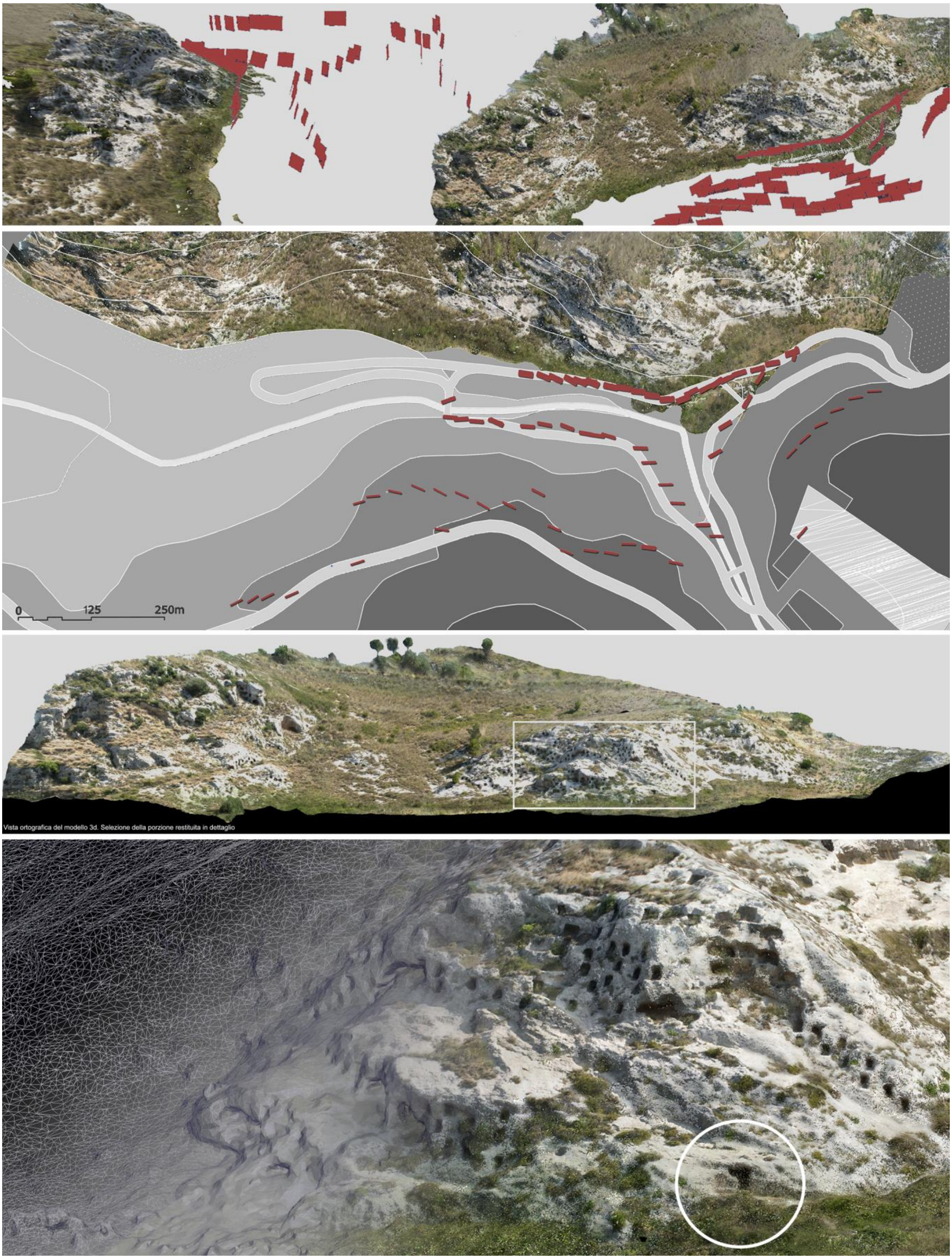

Fig. 7: The Necropolis of Realmese in Calascibetta - (from top to bottom) maps and views of the 3D model with the indication of photos' stations, longitudinal section along the river and identification of the F20 tomb.

Fig. 8: The Necropolis of Realmese in Calascibetta - analysis of the F20 tomb. Example of image-based 3D reconstruction (top), floor plan, sections and views of the 3D model (center) and isometric view (bottom).

Fig. 9: The Necropolis of Realmese in Calascibetta - (from top to bottom) analysis of F20 tomb by 3D laser scanning, phases of the survey and the reconstruction of the longitudinal section from the point cloud.

tracked, analysed, including through the sketch, because there is "a huge difference between seeing something no pencil in hand, and to see by drawing it" (Di Napoli, 2011).

For these reasons the graphic rendering of the floor plan and of the cross-sections of the burials were made with the accuracy of the data coming from technology and the fluidity of freehand drawing, even if put in place by graphic tablet (fig. 10). The strong architectural connotation conferred to the cave by its inseparable relationship with the natural environment could not be represented, in fact, through perfectly continuous lines, without variation in thickness and strength. On the contrary, it needed new expressive modalities, which in this case, trace their origins in the tradition of manual drawing, while being mediated now by the automatic tool.

3.6 The digitisation of archaeological artefacts belonging to the grave goods found in the necropolis

The majority of artefacts found during the excavations carried out by Bernabò Brea on the necropolis are now kept at the Regional Archaeological Museum "Paolo Orsi" in Syracuse, and partly at the Regional Interdisciplinary

Fig. 10: The Necropolis of Realmese in Calascibetta - 2D drawings (plan and cross-sections) of the F20 tomb.

Museum of Palazzo Varisano in Enna. As an example of the procedure of investigation and of their expressive and cultural potentialities, three objects exposed in Enna have been chosen for digitisation: a ceramic jug with circular mouth, a bronze *fibula* in a short span with seven straight cylindrical beads, a bronze cruciform *fibula* with four spirals. Activities were implemented by reverse-engineering technologies with anthropomorphic arm and laser head.

The post-processing has initially provided for aligning the different scans in order to obtain a single point cloud: a synthesis of the spatial complexity of each artefact. The subsequent conversion of the cloud in a polygon model has allowed the elimination of overlapping dots (because common to multiple scans), the optimization of the meshes (more dense in parts rich in detail and larger in parts with more regular curvature) and the integration of the portions which, because of their conformation, were not acquired.

The polygonal models, a “materialization” of the geometric-dimensional information, have enabled the production of profiles and orthogonal projection, of each relic. Thanks to this work, perfectly accurate from the metric point of view, it was possible to measure the real dimensions of each part of the objects and to propose new assessments on their proportions. All this would not be possible with traditional techniques that as less precise, provide information more quantitative that qualitative.

The 3D data capture has granted the full display of virtual models interactively consultable via dynamic .pdf files, so allowing their interactive use, even in the network, to far more extensive users. In addition, the polygonal model has constituted the input data for the subsequent phase of rapid prototyping, i.e. the reproduction of a resin model in scale 1:1, directed to a possible embodiment of replicas for study, museological and tourist marketing aims.

The creation of a prototype allows a different kind of accessibility and preservation of the property. The physical nature and the delicate conservation state of the finds, especially bronze *fibulae*, not allow a risk free manipulation of the objects. The finds, among other things, may, in the course of time, be lost because of their intrinsic fragility.

Replicas permit, on the one hand the conservation of the physical memory of the precious artefact, and on the other hand, they make it accessible to blind users, which would so, be able to handle them and to learn their morphological-dimensional and material peculiarities (fig. 11). Solid models in real scale also are a very useful tool for the design of any museographic media, which must necessarily be studied, developed and constructed in relation to the physical conformation of the object to be exposed, which in this case is very fragile. A reason why the solid model is a good and necessary complement - not an alternative - for the analysis and the understanding of the real object.

4. *Criteria and rules for restoration and enhancement*

Survey activities were finalized to the establishment of a conservation and valorization project of the whole necropolis. From the analysis undertaken emerged that the main problems were related to the state of preservation of the site but also to the physical accessibility of the area of the necropolis and of the caves.

In 2005, the Superintendence of Enna executed a project of valorisation and recovery of the archeological zone. Thanks to this intervention, a

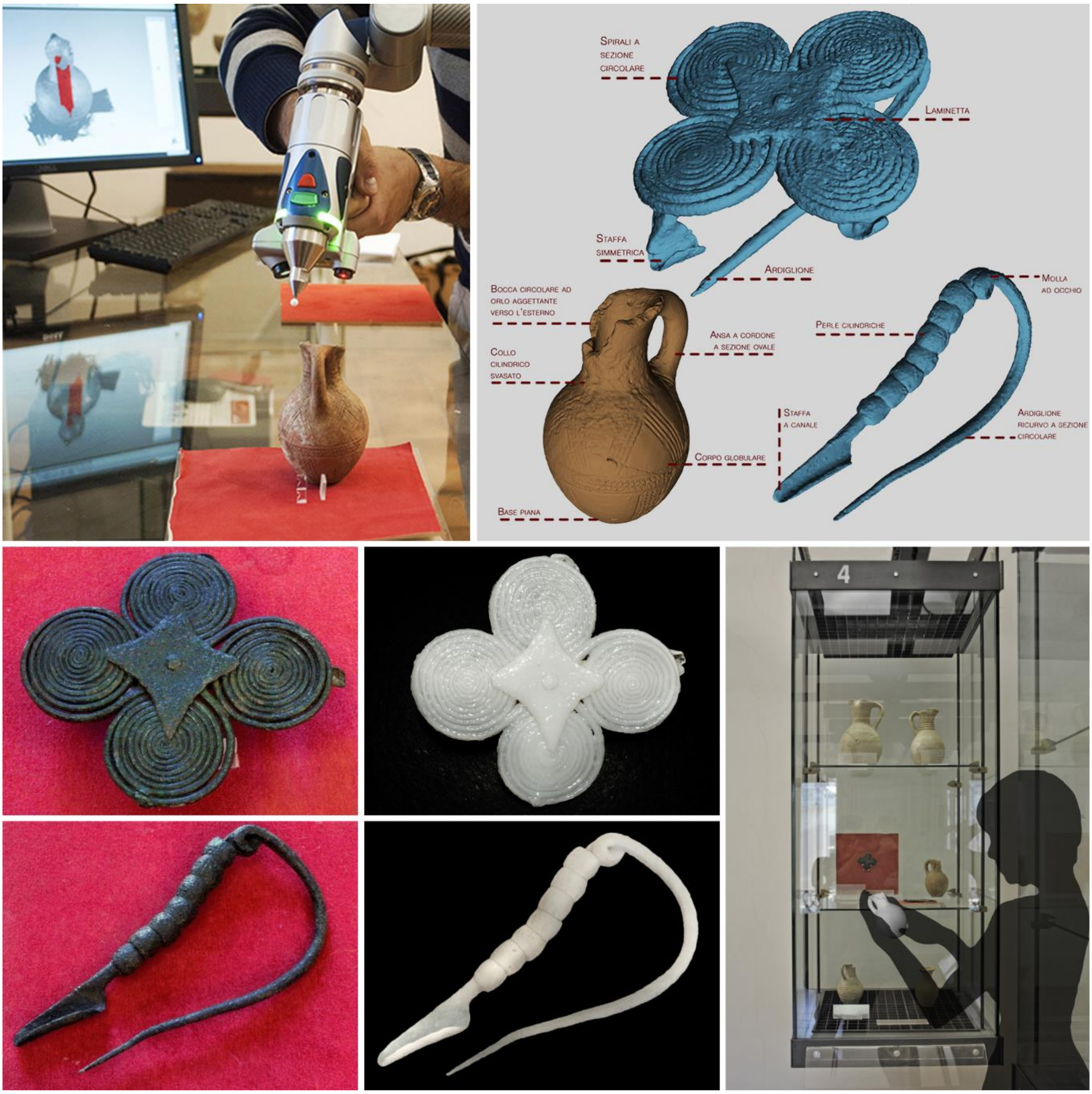

Fig. 11: The archaeological artefacts belonging to the grave goods - (from top to bottom) 3D survey of the individual pieces, virtual models and prototypes, use of replicas for educational and museological purposes.

parking area was set up, the road connection to the necropolis was paved, and paths were realized with footbridges and wooden fences along the ways leading to the necropolis.

The conservation status of the graves is affected by the almost total abandonment of the site, left to the neglect and the natural degradation of the matter. Apart from two panels placed along the route that leads from the parking to the rocky promontory in which are the sepultures, there is no further information on the necropolis. Its knowledge is also almost entirely confined to the local context and mostly excludes the more established regional tourism circuits. Moreover, the infrastructure system linking the site to the city of Enna and Calascibetta is insufficient; in particular, it is to emphasize a lack in public transportation. The written reports related to the necropolis excavations refer to those conducted by Bernabò Brea in the 50s and are known to a few specialists. The related documentation (notes, surveys, catalog sheets and excavation diaries), preserved in the historical archives of the Superintendence of Syracuse, is to date, largely inaccessible because reordering. The bifurcation of the collection in the two museums of Enna and Syracuse, finally, limits the possibilities of study and enjoyment, in an organic way, of all the properties.

Starting from this diagnostic, a conservation project was developed based on the sensitive observation of materials and constructive peculiarities and the careful analysis of deterioration phenomena interesting the rocky outcrop.

The reading and understanding of the state of conservation of the underground environment are closely linked to the use that has been made of. It is very likely that tombs were used in a quite recent period by hunters as temporary shelter and that inside were lit fires.

The combustion residues of coal were the cause of limestone decay. On it there is, in fact, a thin but tenacious crust from deep black color. Below this surface there is a very tender yellowish layer, little adherent to the substrate and easily pulverizable. In many areas of the cave, this in-cohesive area allowed the crust of their backing in larger or smaller pieces under the action of frost, the osmotic pressure of salt crystallization, following a process still ongoing.

The will to not alter the characteristics of this environment, maintaining and highlighting the bumps and irregularities, in total compliance with the principle of minimum intervention, meant that the techniques and procedures to implement would have an impact as limited as possible. For the removal of crusts, for example, it would be appropriate to intervene with clay poultices (sepiolite, attapulgite or bentonite), avoiding the use of water spray, which could affect the nearby pulverized surfaces. On eroded and disrupted surfaces, however, it was considered essential to design a preventive pre-consolidation intervention to allow the subsequent manual cleaning with little soft bristle brushes to use dry for the only removal of deposit powder layers (Lazzarini & Tabasso, 2010).

Stone surfaces are in some cases crossed by fractures with diagonal pattern consistent with the plane of the arrangement of the rock sediment. These discontinuities, although at this time do not constitute a specific problem, may in the future, with the change of the flow path of rainwater, become privileged access points for water infiltration. That is why it was planned the fine-drawn of these fractures, through the inclusion in undercut of modelable plastic substances such as traditional mortar inorganic binders (lime or gypsum) (Torsello & Musso, 2010).

The exterior surfaces are made from limestone rocky ridge subject to the abrasive action of wind and to the run-off and leaching of rainwater. For their protection, the project will involve the use of waterproof and highly breathable silicone resins.

The heavy presence of flora is both a widespread biological degradation factor and a major obstacle to the full use of the site. For this reason, its regulation has been foreseen, also through periodic maintenance. The project also defines the construction of a lighting system at two levels: the first concerning the routes (between the parking and the area of the necropolis and along the paths that skirt the valley) and the second related to the burials.

For the accessible tombs, a specific internal system will be set up. Concerning the global illumination of the entire clifftop, a system highlighting not individual caves but small groups of them will be established, also by putting in evidence the particular morfology of the mountain and the tombs position with regard to the overall system or to the ways through which reach them.

After setting up, as already mentioned, the appropriate conservative treatment modalities, the program aims at indicating primary actions to be taken to allow a wider and easily fruition and its necessary promotion and dissemination. Therefore, the project will be based on the integration of activities directed to the improvement of knowledge, to the incitement of the visit of the place.

Enriched the accessibility of the necropolis through the implementation of the existing signage (internal and external), of the paths and related lighting system, special attention will be paid to the creation of nonexistent services (public reception, ticket office, bookshop) placed within an ephemeral architecture, i.e. characterized by the concept of reversibility that underlies the integrated processes of assembling-disassembling.

A structure, which in a graceful and unobtrusive way, will adapt to a space - currently disused but useful resource for the site's regeneration - made up of the quarry located at the entrance of the site.

This pavilion will also host a small museum/laboratory/library with educational and scientific purposes (addressed to researchers, students and the wider public), which will host the 3D printed copies of the grave goods found on the site and the digitalised documentary archives.

This, not to take over the experience of the visit to the objects stored in the two museums, but rather to encourage it so favoring, at the same time, the understanding of these elements because of their touch-sensorial contact otherwise not possible.

The F20 tomb will be the center of the site tour, becoming the place where the real and the imaginary meet to give birth to new ways of learning and entertainment. Inside, a unique museum will be created: a path through which living the emotion of a journey back in time. Through scenic reconstructions, visual interfaces and holograms, the visitor will be conducted in a virtual dimension, where interactively go through the new opportunities that multimedia technology guarantees to the enjoyment of archaeological heritage.

5. *Conclusions*

The use of new technologies to support the documentation of archaeological heritage does not replace the methods of analysis and cataloguing so far employed. The investigation of a site based on the critical study and interpretation of the sources, both direct and indirect, remains the initial step for its knowledge. However, contrary to the past, today is no longer sufficient. It is actually essential to integrate and complete the wealth of information through the experience allowed by the virtualization of reality by means of immersive images, point clouds and geometric photo-realistic models.

Especially in the case of hypogea, 3D surveying methodologies can be very useful, as they not only facilitate the reading of any cave as singular environment - helping in the identification of carving and excavation traces, technological details, state of preservation -, but also as part of broader and more complex habitats, facilitating the comprehension of the aggregation modalities, the articulation of the interior spaces, the integration with the environmental context, etc. (Tucci, Bonora, Crocetto & Nobile, 2009).

Moreover, the network sharing typical of the digital age, as well as to allow a better understanding and appreciation of a place, can remedy the fragmentation and sometimes the difficult finding of the information related to the research.

A wrong conception leads to consider the 3D documentation such as a simple series of informative contents designed for tourist use. Even many researchers see it as a process to obtain some "special effects" but lacking of a serious scientific background research.

This has partly hampered the use of 3D laser scanning and image-based 3D reconstruction in humanistic studies which have not always grasp the importance of these new tools - rather incomparable if well integrated into the process of knowledge - for the project of preservation and enhancement of our cultural heritage.

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