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POTENTIAL AND LIMITATIONS OF NEW TECHNOLOGIES FOR THE SURVEY OF MORPHOLOGY AND COLOUR OF RUPESTRIAN HABITAT

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Abstract
Regardless of the approach that every subject adopts with the rupestrian habitat, the contribution of new technology products in the practice of surveying and documentation requires a urgent systematisation, both in the operative methods and in the criteria for data diffusion and exchange in order to get a standardised, and homogeneous product, useful to the largest number of subjects. Rock-cut architecture is one of the fields in which a multidisciplinary synergy is well suited, creating a strong innovative drive. For almost a decade the Department of History, Drawing and Restoration of Architecture at the Sapienza University in Rome has been developing research in this direction, both in Italy and Cappadocia. This paper intends to provide a contribution to the knowledge of the problems of surveying and representation that have been faced during the Cappadocia survey campaign, as well as work method and adopted solutions. In particular, the significant pictorial presences encountered in some of the rock-cut churches have focused the research on the issue of surveying the painted surfaces in order to record both the chromatic and the lighting data. This experience demonstrates that behind the apparent operative easiness provided by new technologies, lies a growing need for their deep knowledge that is essential to better co-ordinate and guide their use. Either the obtaining of a good-looking coloured cloud of points or its virtual navigation are not *the survey* but only a proper record of a certain amount of points describing a surface. The representation, as a scientific documentation to be queried for the purposes of knowledge and preservation, comes from the critical processing of such data, that cannot be pursued without an active role of the surveyor.
Keywords: Cappadocia, Rock-cut architecture, Rupestrian habitat, Architectural survey, Laser-scanner.

Riassunto
Indipendentemente dallo sguardo operativo che ogni soggetto, per le sue competenze, rivolge all'habitat rupestre, l'apporto che alcuni nuovi prodotti tecnologici stanno fornendo nella prassi del rilevamento e della documentazione sollecita un'impellente opera di sistematizzazione tanto nei metodi di lavoro che nei criteri di diffusione e scambio, allo scopo di ottenere un prodotto standardizzato, omogeneo ed utile ad un più ampio numero di studiosi. L'architettura scavata è uno dei campi in cui la sinergia multidisciplinare, che scaturisce dall'uso coordinato delle nuove tecnologie, si presta a generare una potente spinta innovativa. Il Dipartimento di Storia, Disegno e Restauro dell'Architettura dell'Università Sapienza di Roma sta svolgendo da anni attività di ricerca in tal senso, sia in Italia che in Cappadocia. Si intende qui fornire un contributo alla conoscenza dei problemi di rilevamento e della rappresentazione che si sono affrontati sul campo, nonché del metodo di lavoro applicato e delle soluzioni adottate. In particolare, le notevoli presenze pittoriche incontrate in alcuni degli ambienti ipogei hanno indirizzato la ricerca verso la questione del rilevamento della forma delle superfici dipinte, perfezionando le procedure di rilevamento polare e di quello epipolare allo scopo di documentare sia i dati cromatici che quelli luministici. Questa esperienza dimostra che sotto l'apparente semplicità operativa fornita dalle nuove tecnologie si cela la crescente necessità di una loro conoscenza profonda, al fine di poterne meglio coordinare e guidare l'utilizzo. L'ottenimento di una gradevole nuvola di punti colorata o la sua navigazione virtuale non sono il rilievo ma solo la corretta registrazione di una certa quantità di punti che descrivono una superficie, l'immagine di una pelle. La rappresentazione, in termini di documento scientifica ed interrogabile ai fini della conoscenza e della conservazione dei beni, nasce da una elaborazione critica di tali dati che non può prescindere dal ruolo attivo dello studioso e da criteri comunemente condivisi riguardo non solo la loro trasformazione, ma anche la loro acquisizione.
Parole chiave: *Cappadocia, architettura rupestre, habitat rupestre, rilievo architettonico, laser-scanner.*

Introduction

The activities for the *preservation* and *development* of the architectural heritage are invariably based on the knowledge of the artefacts, as well as the productive and cultural processes that generated them. Only the Architectural Survey, which is today intended as "an open system of knowledge" (Cundari, 2012; Inglese & Bianchini, 2010), offers the bases necessary to plan any future action upon the architectural heritage.

The figure of the surveyor has recently established itself as the most appropriate to translate the physical reality of a historical artefact into a systemic set of data and visual models useful for its knowledge as well as for possible planning for its preservation and development (Docci & Maestri, 2009). It is needless to emphasize that the advent of computers and laser measuring devices has profoundly altered expectations, outcomes and operating procedures of architectural survey, making it possible to approach the study of artefacts and places which were considered too complex or simply inaccessible by the traditional tools and techniques (Carpiceci, 2013a).

This is especially true for underground and rupestrian structures, often neglected even by scholars and

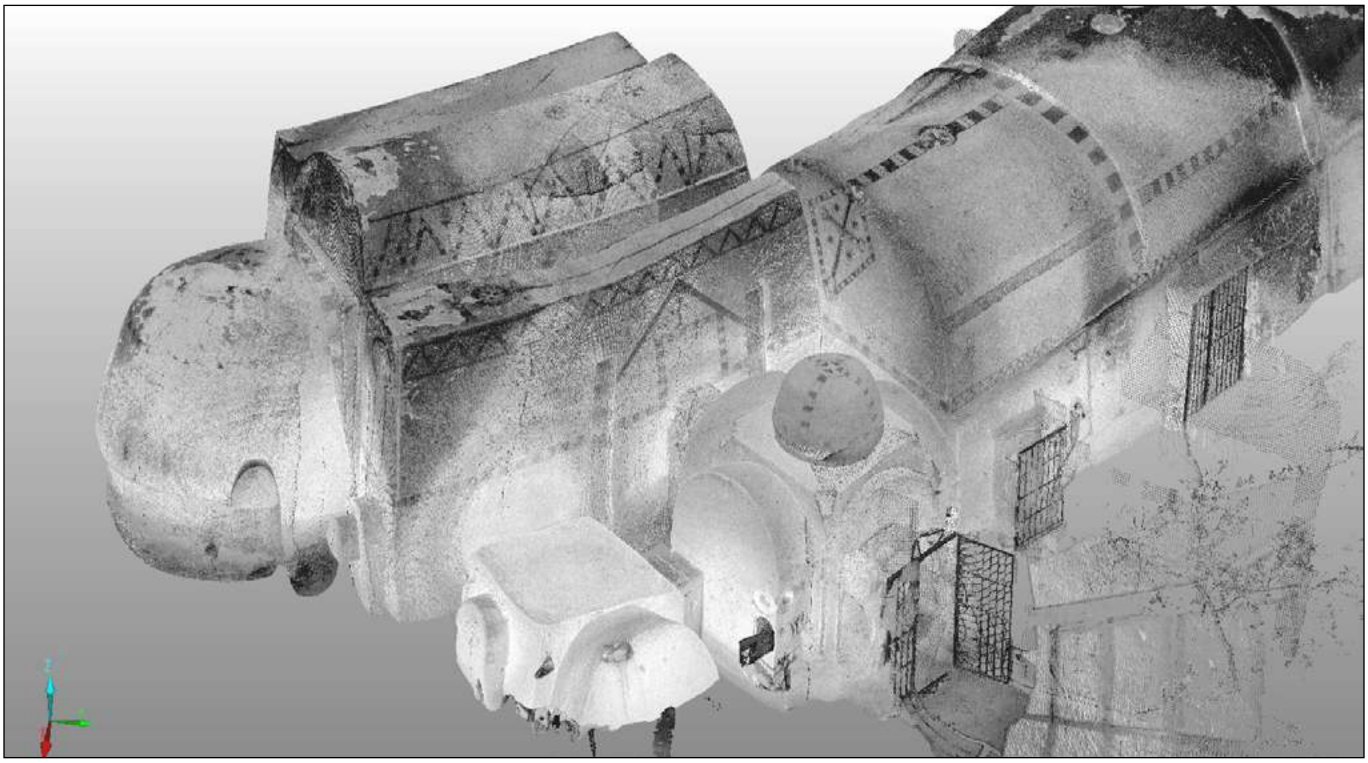

Fig. 1: Göreme, Aynalı Monastery, church and other rooms. The assemblage of different scans offers a vision of the excavated intrados surfaces (image by M. Carpiceci).
Fig. 1: Göreme, Monastero di Aynalı, chiesa ed altre sale. Il montaggio di differenti scansioni offre una visione delle superfici di intradosso scavate (immagine di M. Carpiceci).

surveyors, both because of the difficulties inherent in their form and position, and for a certain cultural attitude to consider primarily, if not exclusively, the visible and emerged part of a building (with the consequence of neglecting not only the quality of the masonry and interspaces, but the more general functional and constructive relationship that exists between a building and its lower structures).
While for several years the digital photography combined with versatile drones are pointing the way of sky as a new opportunity to study roofs and cusps of the buildings, the laser scanner is joining photogrammetry and topography in the surveying of underground spaces. Indeed, precisely the rupestrian architecture, with its irregular surfaces, furrowed by the signs of the manual excavation and eroded by weathering, appears today as the most ambitious and rewarding challenge for the latest scanners.

Surveying the form

The *form* in a laser scanner survey is all that is measured by a *polar* scanning and subsequently stored as a series of points in a set of Cartesian coordinates. The accuracy of the measurement can be affected by many factors derived from the physical nature of the object, such as lucidity, consistency or presence of edges[1], but the rapid evolution of technology is continuously overcoming these obstacles (Carpiceci, 2012b).
For some years the lightness and portability of the latest laser scanners is allowing to carry and use these tools in tight and uncomfortable spaces, like tunnels and catacombs. This is the case, for example, of the model FARO Focus3D 120, adopted by the authors in the context of the research dedicated to the rupestrian habitat of Cappadocia (Carpiceci, 2013b).
Moreover the scanner laser mechanism allows its use even in a complete darkness, and this is a great advantage for those who normally had to carry around heavy electric generators, lamps and wires.
The experience in Cappadocia, however, allowed us to test the effectiveness of the laser scanner both in the most usual and chaotic conditions of monuments visited by thousands of people every day, and in the difficult conditions offered by sinuous tunnels, oblique wells and dusty caves almost inaccessible to the public. In the almost total absence of sharp edges, inevitably eroded by the wind, and other high-recognizable architectural elements, scan operations have been systematically carried out with the aid of the spherical references useful to incardinate subsequent scans and to facilitate their assembly assemblage in the post-production.
In the laser scanning practice the survey design phase is commonly overlooked in the name of the extreme power of the tool: indeed, generally the surveyor secretly hopes to solve its commitment with one single scan from the centre of the room, moving only to understand where the scanner is to be placed in order to cover most of surfaces. Further, locating with precision the spheres, which might seem a waste of time and energies, plays

1) Nemesis of laser scanning is represented by a room with coloured, matte and glossy surfaces, mirrors, metal structures with sharp edges, sculptures in plaster, wax and obsidian; all *topped off* with a mixed lighting of incandescent lights and neon. In such a case, a laser scanner (as well as the photo-modelling) would be totally helpless (Carpiceci, 2012a).

a role that today is often underestimated. First, it forces the surveyor to plan the sequence of scans with particular attention because he/she needs to move or to leave this or that reference. In addition, it offers the surveyor the opportunity to measure the space with the body, to have an experience that no matter how fast and unconscious, is a fundamental critical reference in the subsequent processing steps of the survey.

Despite the hours spent in the caves looking around and waiting for the scans, the results have been often surprising. Only after downloading and assembling the clouds of points on the computer, the different levels of environments revealed their actual shape as well as all their formal autonomy. The three levels that constitute, for example, the monastery of Aynalı, ignore each other even if they are correlated with wells and stairs. This feeling of alienation is amplified by the fact that the ancient builders tried to recreate the look of traditional built rooms and halls, as can be seen in many churches (Fig. 1).

Neither evident attempt to create rational space systems can be detected, nor panoptic centres to visually control a number of rooms and corridors are observable. Both oblique wells and curved stairs prevent from seeing the end of vertical connection. Of course countless crashes and frequent alterations due to changes of use have undermined the chance to reconstruct with certainty the original forms of the settlements. Moreover ancient builders used to dig following the external limit of rock in order to best exploit the portion closest to air and sunlight.

However, not only each room seems to have been developed on its own but corridors, stars and other connections are generally curved. In this way the reassuring perspective of an enfilade is systematically prevented. Besides recalling similar urban developments, which affected many Italian and Mediterranean villages, the shape of these space systems is an intrinsic impediment to the probing straight laser beam of the scanner, avoidable only by increasing the number of the scans.

Yet perhaps the most significant moment of such a reproductive and knowledge process, is the assemblage of the clouds of points relative to the interior rooms with the exterior surfaces. The ability to visualise and measure, even partially, the changing and unpredictable relationship between extrados of the cones and intrados of the caves, return to the artefact, natural and manmade at the same time, the value of an effective architecture that can be finally compared with many other architectural human expressions. Secondly, the external scans, if repeated over time, can ensure a monitoring of rock movements that is useful to manage at least the preservation of the artistically and historically significant cones.

The scanner can even surprise the surveyors, revealing the existence of elements they had not seen in their former inspection. This is precisely what happened during the most recent campaign of surveys carried out on September 2014. When assembling the scans necessary to obtain a complete model of the Aynalı monastery, one of the many architectures recorded in recent years, the existence of a narrow channel of aeration was revealed: it was undetectable in the light of the flashlights but the scanner readily revealed and translated it into the point cloud. Another significant discovery was made by varying the number of dots per inch to be scanned. By increasing their density it was possible not only to reproduce the general mould surfaces but also the small furrows left by remote diggers, and consequently to record the different excavation processes that often correspond to different stages or epochs (Fig. 2). The experience of the scanner in Cappadocia thus demonstrates that, with proper settings, the point cloud data may record not only the current form of these environments but part of the process that generated them in time. At the same time, it recorded the most evident cracks, rather frequent in the friable tufa constituting the majority of the excavated architectures. The sharp-edged cracks are generally the most recent ones and, if appropriately decoded, they are able to reveal the likely future evolution of rock-cut habitat. A laser scan, in this specific case, is thus a document capable to capture the present state, along with information about the past and possible future of a monument.

Lighting, colour and plane representation

Beyond the form, a primary aspect of rock-cut architecture, another feature is hard to classify and almost impossible to resolve: the colour. It is worth noting here that colour can be considered *everything that is not form*. First of all the specific colour of the rock should be considered: it mostly outside repeats and amplifies the difficulty of its proper recording, with nuances given by the inhomogeneity of the material and the variations of surface geometry.

On the rock of the Cappadocian cave architectures different painted layers are commonly found. Peculiar red geometric paintings often mark rock surfaces hewn in imitation of architectural elements such as capitals, mouldings, *pendentives* and vaults. Even if those signs appear so hurried and unsystematic they are assumed to employ an apotropaic function: they were possibly placed by the builders at the end of the excavation in order to seal and celebrate, at the same time, the end of the architectural envelope. In this hypothesis, they are to be considered as an integral part of the architecture, both for their liturgical, doctrinal and narrative meanings and for their valence of chromatic *signifier* attributing a fictional structural role to single geometric elements: although physically fused with the whole, single parts appear to be separated from the contiguous surfaces and assume the function of arches, pilasters, columns, capitals, vaults, etc. In a certain way, those red paintings represent the architectural project designed in a decorative form directly on the subject, as if it were a *maquette*, a full-scale model (Fig. 3).

As an integral part of the overall architecture, such paintings cannot remain ignored or underestimated. The problem that occurs is how to survey and represent them.

A laser scanner today can measure both the spatial

Fig. 2: Göreme, Aynalı Monastery, NE room, detail of the cloud of points. In the middle the hole of an aeration conduct connecting the room with another room two levels above. On the walls the pseudo-circular carved traces of excavation are shown (image by M. Carpiceci).

Fig. 2: Göreme, Monastero di Aynalı, sala a nord-est, dettaglio della nuova di punti. Nel mezzo il buco del condotto di areazione che collega la sala con un'altra posta due livelli più in alto. Sulle pareti sono visibili le incisioni pseudo-circolari di scavo (immagine di M. Carpiceci).

and the lighting conditions: it records not only the position of the points that constitute the rock surfaces but also their *reflectance* (or reflectivity) and the RGB components. Nevertheless, it is not enough to activate the *colour* option on the tool to get the perfect colour measurement of surfaces. In fact, the factors that determine the appearance of a surface are multiple and, sometimes, very difficult to control. Besides the form, it is necessary to consider two other crucial parameters: the *surface appearance* and the *lighting*.

The *surface appearance* is adjustable by means of two measurements. The first is internal to the scanner, which measures, in addition to position of the point in space, also its *reflectance* or, to better say, the *apparent brightness*. In the darkness laser *lights up* the surface and measures the percentage of reflected light (*reflectance*) but external sources such as natural or artificial lighting may affect its results. Scanning in the darkness surely allows the best recording of the reflectance of the subject. Alternatively a more uniform lighting condition must be found, like a large area of shadow or the presence of cloudy skies. Any source of light, either artificial or natural, that causes an alternation of illuminated and shadowy areas on the subject, makes the reflectance value only a *decorative* pattern.

A laser scanner can also record the colour in its RGB components. At the end of the scan, an apposite sensor inside the scanner detects the visual sphere by performing a defined number of pictures that can then be used to *colour* the cloud of points automatically recorded. This operation replaces the black and white image with a coloured one, giving the scan the realistic look of the subject at the time of scanning (Fig. 4). It is important to underline that such a realistic look is the result of the contingent interaction between light and subject, which varies constantly under varying lighting conditions.

The point clouds, appropriately decimated and covered with triangular polygons, are an effective support for the application of photographic maps, but if the photos are of poor quality they are likely to affect the final visual outcome of the survey. It is therefore always advisable to keep a copy of the model *dressed* with the only reflectance values to be able to process with appropriate auxiliary images executed with the intent to record as closely as possible the actual colour appearance of surfaces.

In the case of painted surfaces, the purpose of an architectural survey is also to offer the actual status of the architectural substance in its chromatic feature regardless of the illumination present in that specific moment. The chromatic scanning gives the *certainty* that each measured point can be *dressed* in colour but with a result that is inevitably disturbed by the lighting present. Such a result cannot be accepted for a scientific product and a different chromatic survey procedure should be pursued. Certainly also a colour picture, taken independently from the scanner, needs some kind of light, but this can be arranged according to specific requirements depending on the condition of the place.

Fig. 3. Göreme, Open Air Museum, Azize Barbara Kilisesi (Church of S. Barbara), zenith vision of the central dome and barrel vaults (photo by M. Carpiceci).
Fig. 3. Göreme, Open Air Museum, Azize Barbara Kilisesi (Chiesa di S. Barbara), vista zenitale della cupola centrale e delle volte a botte (fotografia di M. Carpiceci).

There are two factors to be taken into account, one technical and the other technological. The technical factor is perhaps the most important and concerns the number of steps to follow in order to get the right amount of useful material to colour dressing of the cloud. To cover all surfaces of which one intends to record the colour appearance and avoid any shadows, it is first necessary to analyse the morphology of the subject. Photographic images should have the same relationship with the original scale: with the same focal length, the camera can be kept at a constant distance from the subject while varying the focal length, and the camera must be proportionally moved closer or farer. The lighting should be as uniform as possible, so as to eliminate any form of shadows or *chiaroscuro*. Minor shadows can be adjusted in post-production with manual correction of the shot, both by the simple retouch of either darker or lighter areas and by changing the local dynamic range. The photographs of the interiors should finally be optimized through the use of appropriate flash and screens while outside pictures should avoid the prospects directly illuminated by the sun and, when possible, wait for the scattered light that is realized under an overcast sky.
As regards the technological factor, linked to the evolution of the equipment, the advice is to look for the highest quality, with more portability: for example, a full-frame camera with interchangeable lens (preferably fixed-focus lenses), *live view* and at least 20 megapixels, possibly without anti-aliasing filter.
This special attention to the colour survey becomes essential when not only geometric paintings completing architectural complex are considered, but also the delicate figurative frescoes that are placed not on flat smooth surfaces but on varied surfaces carved into the tufa (Fig. 5). These painted surfaces need to be represented in their *true form* to facilitate their correct reading as well as their use in restoration and preservation operations (Carpiceci, 2011). Therefore it is imperative that the scientific community predisposes software capable of processing images for the clouds to obtain correctly developed and elaborated surfaces. We know that flat walls, or *approximately* flat walls, may already have this form of processing. The ruled surfaces, while having easy processing capabilities were not (with rare exceptions) the object of attention of software houses. Both spherical surfaces and complex ones have the medal of a complete oblivion; but something about it was recently suggested (van Wijk, 2008).

The operating procedures: comparing methods

The experience led in the rupestrian habitat of Cappadocia demonstrated that beneath the apparent

Fig. 4: Göreme, Open Air Museum, Çarıklı Kilise (Sandal church), perspective view of the cloud of points with photographic map (image by M. Carpiceci).
Fig. 4: Göreme, Open Air Museum, Çarıklı Kilise (Chiesa dei Sandali), vista prospettica della nuvola dei punti con mappatura fotografica (immagine di M. Carpiceci).

simplicity of operation provided by new technologies, lies the growing need for their profound awareness. A surveyor should not be a mere user of those tools, but should be able to coordinate and guide their use. The vision of a *eye-catching* coloured cloud of points or its virtual navigation *are not* the survey but only the proper registration of a certain amount of points describing surfaces that is the image of a skin (Fig. 6). The *representation* in terms of a scientific document to be queried for the purposes of knowledge and heritage preservation, is the result of a critical processing of such data: an active role of the scholar cannot be ignored as well as commonly shared criteria regarding not only their transformation, but also their acquisition.

The survey of rock-cut architecture also provided the opportunity to test a different operative method to be compared to that commonly used within the Department of History, Drawing and Restoration of Architecture at Rome. This was tested and developed on numerous case studies, with the ultimate goal of structuring a protocol to be applied, with the necessary changes, to a large number of different case studies. As a general concept, such a protocol is based on some basic steps: analysis and goal setting, surveying and processing. It is important to emphasize how the idea of a protocol does not have the purpose of making the surveying a mechanical process, but rather to arise as an aid and critical reference that the surveyor can use to optimise the entire process: its final function is to allow upstream the choice of a procedure that is compatible both with what could be called the *scale* of the final model to study and play with the different techniques and with the characteristic morphology of the object. It is clear that, in this case, approaching spaces obtained by *subtraction* of matter rather than by *addition* and *assembly* of parts, it was necessary to check and revise a protocol formed mainly on examples of more traditional architecture. On the other hand, Cappadocian rock-cut architecture generally prevents the surveyor from defining where a wall ends and a floor begins, as well as to distinguish a significant niche from an occasional hole: it actually prevents him/her from analysing and discompose the built structure following usual operating methodologies. Similar problems are found when representing the collected data, both for the difficulties involved in graphically describing the rock surfaces at different scales, and for the different purposes drawings and models be able to respond to. The participation in the research group of different specialists - geologists, speleologists, art historians, archaeologists - favoured procedures to be tested according to the specific needs of different scholars and in particular to decline and optimise the final results according to most types of processing.

For example, the specific request by art historians consists in the possibility to obtain models that can allow a more detailed study of the stratigraphic and historiographical problems in the understanding of the whole architectural object. However, only after a careful analysis of logistic, a major project should been designed to be compatible with the site, the peculiar geomorphological characteristics, and with the *object*, of course.

These two aspects have placed a number of issues hard

Fig. 5. Göreme, Open Air Museum, Tokalı Kilise (Buckle Church), upper part of north wall of transept, photo-plan with the highest shadows attenuation (photo by G. Alfano).
Fig. 5. Göreme, Open Air Museum, Tokalı Kilise (Chiesa della Fibbia), parte superiore della parete settentrionale.

to be solved with the usual procedures based on the integration of different methodologies, such as: survey with total station, survey with 3D laser scanner and photographic survey (Docci, 2005; 2007). The survey with total station set to a closed polygonal[2] allows seizing rigidly the whole building and constitutes a support and verification for subsequent scans made with the laser scanner[3].

In this type of integrated survey each procedure is related to the other in order to exploit the potential and optimize the results. Such a survey should produce *a numeric objective* model capable of describing uncritically the entire architectural structure and to constitute itself a first data to be analysed (Bianchini, 2001; 2007; Inglese, 2012). The equipment supplied by the Department of History, Drawing and Restoration of Architecture and commonly used for such works, involves a 3D Laser Scanner (Leica ScanStation C10 or 2) and a Total Station (Leica TCR 1201 R300 Type or TCR1800).

As mentioned, the complex geomorphology of the site together with the morphology of architecture characterized by the almost total impossibility of determining a *geometric model*, suggested the use of another procedure bypassing the traditional *mensoria* practice defined by the usual sequence: scanning, numeric model, geometric model, representation through orthogonal projections. The use of light instruments, such as the aforementioned 5 kg-heavy laser scanner Faro Focus 3D, offered the opportunity to climb smoothly along the cliffs, thus avoiding the transport of unnecessary tools. The potential offered by this instrument allowed to renounce to the total station: structuring inter-polygonal has been substituted by a systematic use of reference balls. The recognition of homologous points, non-specific but seen in more scans, was used for registration of the clouds. In fact, the laser scanner measures points according to a polar geometry concept (distance, horizontal angle, vertical angle), like a total station and then features already included in the laser scanner have been used in place of topographic procedures. One of the advantages of this methodology is the opportunity to perform *compensations*, in general possible only in closed polygonal, through the registration of the clouds via the automatic recognition of a large number of points.

The use of contour lines is to be favoured as the priority form of description of the rock-cut architectures to be used in the graphic rendering phase, which takes place after the transformation of the cloud of

2) Usually a topographical survey is based on a closed polygonal sequence of stations shooting points materialized by easily identifiable targets.

3) Generally a first general scan with a Sample Spacing of 3x3 cm is dedicated to the acquisition of the entire or large portions of the artefacts and a second detailed scan with a more dense Sample Spacing equal 2x2 mm is typically dedicated to a specific target.

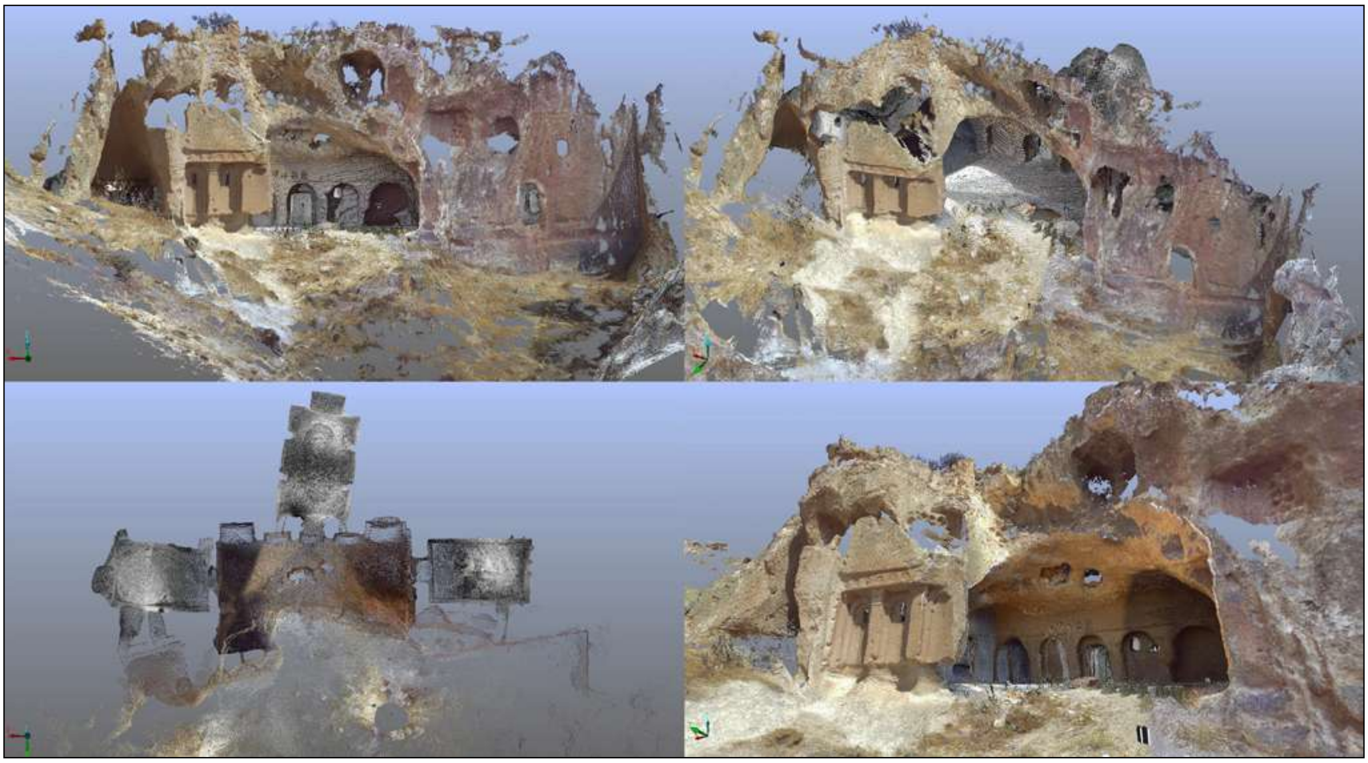

Fig. 6: Şahinefendi, Monastery, four views of the cloud of points with RGB data maps (image by M. Carpiceci).
Fig. 6: Şahinefendi, Monastero, quattro viste della nuvola di punti con mappatura cromatica RGB (immagine di M. Carpiceci).

points into a surfaces model (CARPICECI et al., 2014). A description through horizontal sections at different heights is necessary for the understanding of the relationship between exterior and interior spaces; in particular a contour interval of 10 cm in 1:50 scaled representation provides the best compromise between metric-descriptive density and readability of morphology (Fig. 7).

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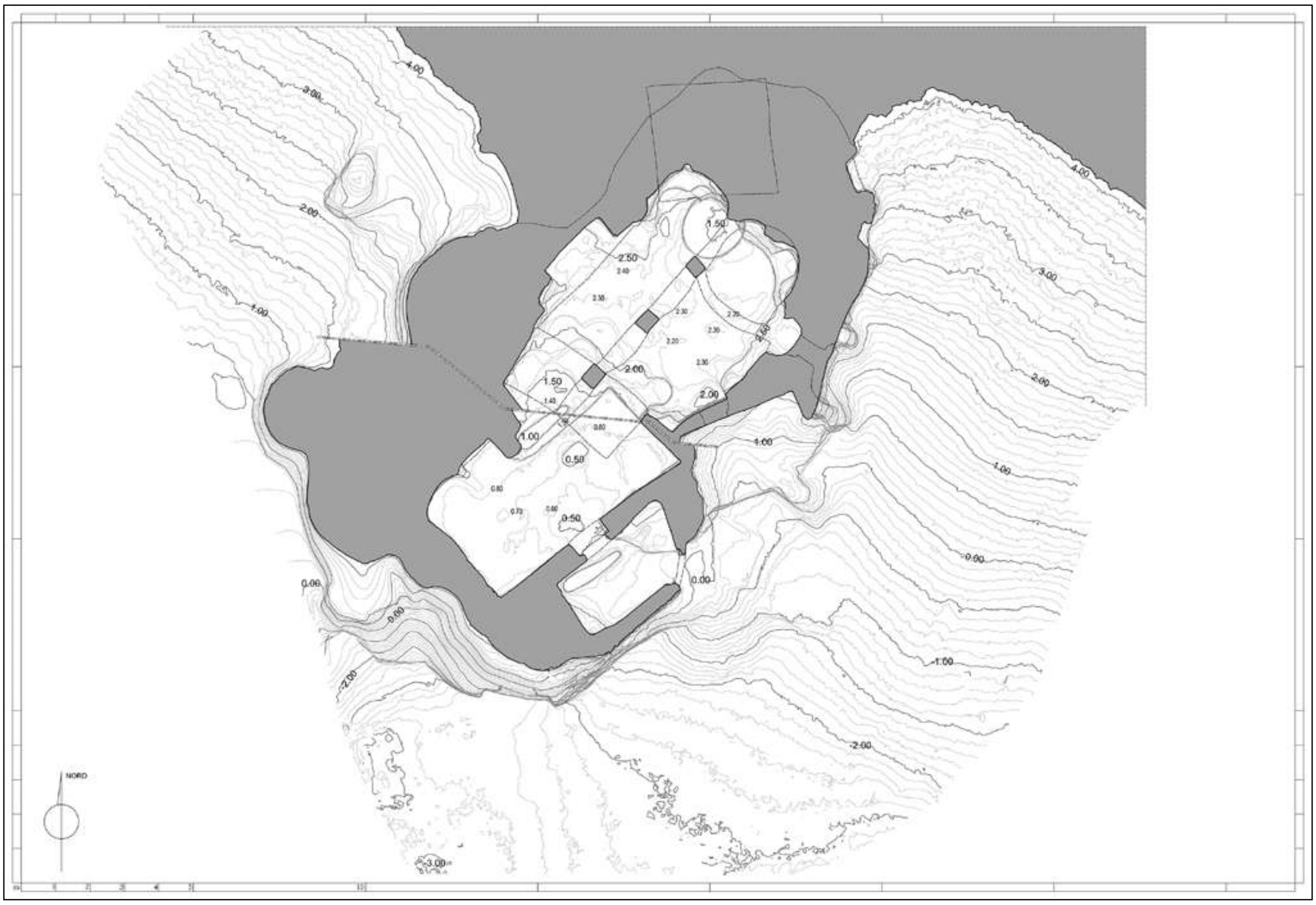

Fig. 7: Şahinefendi, Church of the Forty Martyrs, plan (horizontal section) of the entrance level, representation by contour lines with an interval of 10 cm (drawing by M. Carpiceci).

Fig. 7: Şahinefendi, Chiesa dei Quaranta Martiri, pianta (sezione orizzontale) del livello di ingresso, rappresentazione per curve di livello con un equidistanza di 10 cm (disegno di M. Carpiceci).

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