

# The Digital 3D Survey as Standard Documentation of the Archaeological Stratigraphy

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## Abstract

*In this contribution we describe tools and methods used to perform three-dimensional photogrammetric survey of different archaeological contexts. In particular, we studied in depth some aspects: swiftness (of the proceeding), accuracy (of the measurement), informative contents (of the registration) and cost (of the instruments). Considering these factors we propose some solutions for the integration of photomodelling and stereophotogrammetry within the current standards of archaeological documentation. The first part will show three-dimensional photomodelling examples of walls stratigraphy and structural elements. Then follows the comparative analysis of two different technique of survey for the documentation of the same archaeological context: the direct detection and the stereophotogrammetric one of a burial. The second part discusses the first results of an experiment still in progress: the documentation of all the contexts identified during an archaeological excavation by stereo-detection. The contribution closes with an experience of photogrammetric survey of petroglyphs.*

Categories and Subject Descriptors (according to ACM CCS): J.2 [Physical Sciences and Engineering]: Archaeology

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## 1. Introduction

In recent years, the “point cloud survey” have involved an increasing circle of researchers in the field of archaeology and, more generally, of conservation of cultural heritage [ABB\*09, BBC\*04, BM07, CCDS09, CF06, DMV10, Fio10, Fio09, Jes04, Mat08, Mig01, VFS08]. Thanks to many attempts we are identifying benefits and limitations of instruments capable of automatically measure a large number of points (three-dimensional scanning devices, stereophotogrammetric systems and latest generation of motorized total-stations). In our opinion, however, there are at least two points that still need to be explored: the need to define new operative protocols of archaeological survey focused on the use of these particular instruments and three-dimensional graphic representation as a source of useful data for the interpretation of archaeological and historical contexts. The first issue has recently been detailed at the workshop *L'Informatica e il metodo della stratigrafia* [VFS08]. On that occasion it became clear that, while the new tools provide more accurate and massive data collection compared to classical methods, however, they struggle to integrate into the daily work of the

archaeologist as they are still too expensive, difficult to apply for the duration of the excavation or unfit for detection of specific contexts. In regard to the second theme, it is evident that in recent years efforts have focused almost exclusively on finding the most appropriate method for the acquisition of data (metric and photographic), neglecting graphical representation and its use in archaeological research. Very often we offer, in fact, photo realistic models that leave out all the characters that really matter for the archaeologist (stratigraphy and structural elements). In our opinion, however, the use of these new tools should lead to the creation of documents graphically similar to traditional ones (plans, sections and elevations), but with the added value of showing the three-dimensional component of the archaeological data (Figure 1). These representations allow us to observe and compare simultaneously all parts of the archaeological context and to quickly check similarities and differences of formal and stratigraphic features. The characterization of “stratigraphic model” using GIS tools also ensures a clear and effective communication of the results of archaeological investigations (e.g.: a distinct staining of the stratigraphic surfaces belonging to construction phases) (Figure 2).

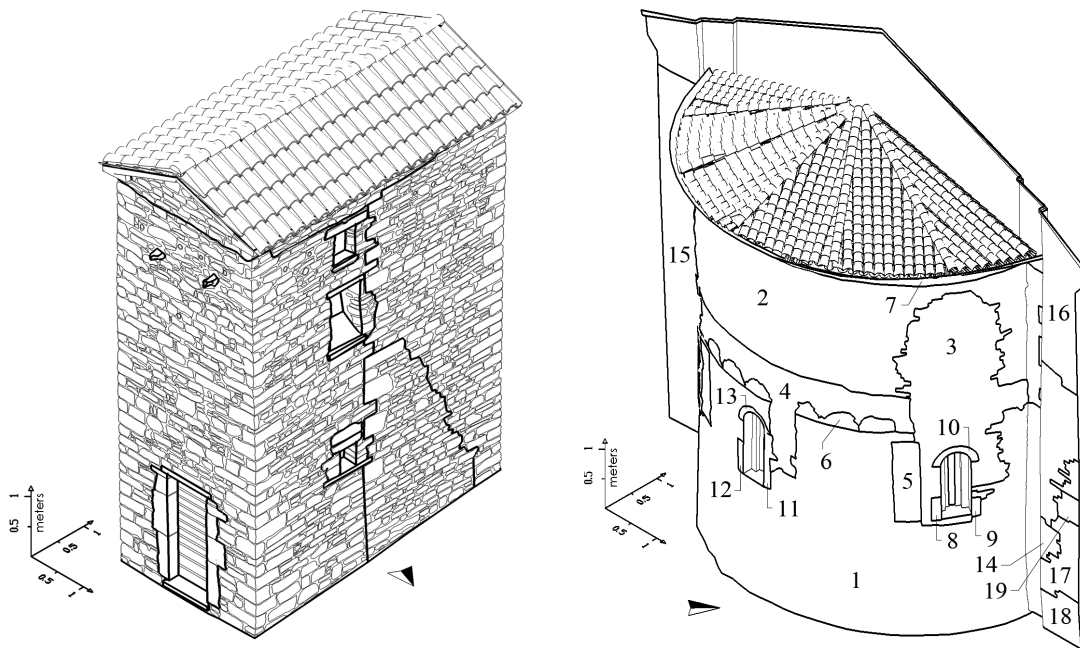


Figure 1: Three-dimensional survey of wall stratigraphy.

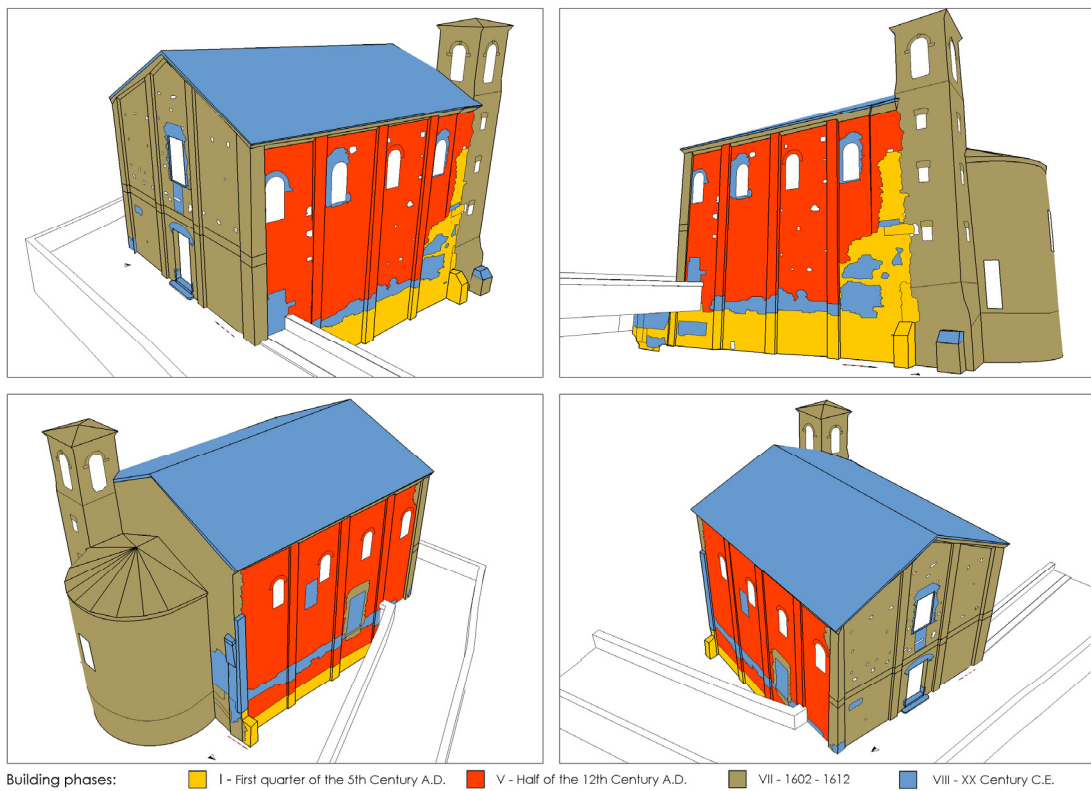
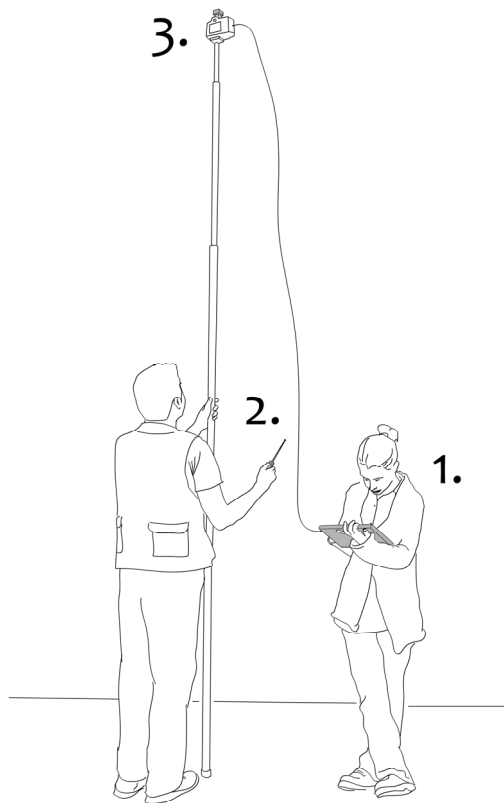


Figure 2: Three-dimensional survey of wall stratigraphy with identification of different building phases.



**Figure 3:** *Photographic system: 1. the monitor provides the scene framed by the camera 2. via wireless radio control one can control the camera shutter; 3. the receiver is set on a digital SLR.*

As for the survey of high preserved buildings the operation sequence developed in recent years is based on the Eos Systems software Photomodeler Scanner (henceforth abbreviated PMS) [FA11]. With this program it is possible to reconstruct the surface of any object in two different ways: from points in common identified on at least three photos taken from different positions (photomodelling) [De09]; starting from “point cloud” generated by stereo pairs (digital stereophotogrammetry). We use a digital SLR camera fixed on different structures to make the photographs: a telescoping aluminium pole (for very tall building) (Figure 3) and a metal rod (linear guidance of 1.4 meters) that is placed horizontally on a photographic tripod. On this rod a cursor on which one can tightly bind the digital camera can slide freely. The latter, once locked on the sled, can be moved along the metal rod by hand (Figure 4). After surface rebuilding, one can run three-dimensional drawing of any recognizable object on the photographic images (e.g.: context perimeters and structural elements). This way the lines (one-dimensional geometric entities) and polygons (two-dimensional geometric entities) that are created have the size, orientation and position in three-dimensional space of the real objects they represent.

## 2. The three-dimensional graphic representation of structural elements and wall stratigraphy: case-study of the tower of Montalto (Premilcuore – FC – Italy)

The detection activity is part of a research project that aims to define new standards of archaeological documentation based on the use of photogrammetric techniques. Three-dimensional representation of structural elements and wall stratigraphy of the tower of Montalto was obtained using PMS.

The detection technique takes into account the formal characteristics of the building. Although the total surface of the tower appears rather irregular, due to structural deterioration, the exterior and interior wall hangings do not have curved or protruding or falling architectural elements. These features have suggested to model the wall surfaces using the vector graphical representation of the edges bounding the faces of the elevations and architectural elements. It means that the surfaces generated inside edges are flat and do not record any irregularities or local curvature. This process of formal synthesis, however, has not led to a significant loss of information. On the other hand, convincing results on irregular or curved shapes can obtain by using “point clouds” generated by stereo-pairs in PMS. The acquisition of necessary data to the survey has covered a period of about 3 hours. The instruments used were an aluminum ruler equipped with twin bubble, hard plastic balls (diameter 0.4 mm), small clay discs (diameter 1 cm), a tape measurer, a telescopic aluminum pole and a Nikon D7000 (CCD sensor with 16 million effective pixels) provided with calibration certificate.



**Figure 4:** *The photographic tripod used to perform stereo-pairs.*

First, a fairly large number of targets have been materialized on the wall surface (plasticine® discs with a central hard plastic ball). This preliminary step is essential for the proper functioning of PMS which calculates the spatial position of any object in the picture when operating the identification of common points (Referenced Point). In the next phase of work were established handhelds photo. Thanks to some previous experiences of detection on similar buildings, it was decided to capture every elevation

of the building from at least three different viewpoints: a central photo (axis as perpendicular as possible to the surface) and two converging ones (axes inclined with respect to the surface). The photographs were taken at a distance of about 6.8 meters from the surface (with a minimum distance of 5,2 m in oblique photos and a maximum of 8,6 m in orthogonal shootings) fixing the camera on top of a telescopic pole. In this way, it was possible to keep the holding point as close as possible to the center of each elevation by compensating strong gradient of the ground. A total of 29 photos were made: 18 shots were used to model the interior and exterior elevations and 11 for the ridge walls. The next step was to identify the correspondences between the pictures (Referencing) by placing X shape symbols (Marked Point) over all the targets visible in the photographs and selecting those that refer to the same physical object. At this point it was possible to initiate the process that calculates the spatial position of the Marked Point (now converted to Referenced Point) and evaluating the quality of the project (Final Total Error). In this case the total error obtained was 0.6 further reduced to 0.5 after the process of elimination of the distortion introduced by camera optic (Idealization). To assign the real size and the correct spatial orientation to the model it was necessary to measure with the total station the spatial position of at least three targets and then assign the corresponding three-dimensional coordinates to Referenced Points. After rebuilding the surfaces of the architectural structure, we moved to the enrichment of information level of the model by operating three-dimensional representation of all structural elements and wall stratigraphy. Thanks to the "link" between images and surfaces, "real-time tracing" on the photo the perimeter of any element, the software calculates position, orientation and real size. The "stratigraphic model" was finally loaded into ESRI®™ ArcScene to develop three-dimensional views to communicate clearly and effectively the results of archaeological investigation as the membership of each stratigraphic unit at different building stages (Figure 5).



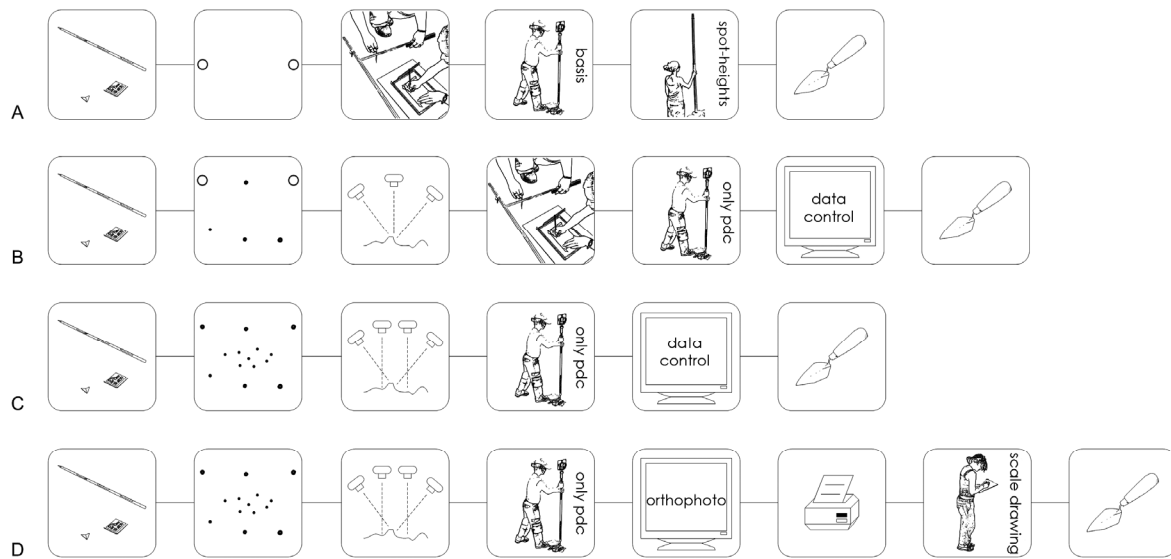
**Figure 5:** *Three-dimensional survey of wall stratigraphy with identification of different building phases.*

### 3. Stereophotogrammetric detection of burials: proposals for integration in the current documentation standards

When drawing a skeleton by means of a double standard slat the method of survey for abscissas and ordinates can happen to suspend the operations of excavation for over an hour [Fio08]. The bones are drawn and one takes spot-heights on the skeleton itself by measuring the position of a lot of points. The extremes of the baseline (materialized on the ground, for example, by 2 plastic bottle caps) and at least 2 stakes of the general grid are detected with a total station. An optical level or a total station can be used for recording spot-heights (Figure 6, procedure A). In this case, it is possible to reduce the execution time without affecting the accuracy of the measurement, introducing some variations of the method. The first solution does not change the nature of the drawing (which is manual), but will skip completely the detection phase of the spot-heights (Figure 6, procedure B). The second further reduces the time because it proposes to carry out the detection by computer (Figure 6, procedure C). The first solution is based on photo-modelling (three shots: one zenithal and two oblique), through which it can obtain the quota of each visible point in the three photos. In practice, in half an hour one can materialize on the ground 6 control points (pdc), using total station to measure the position of at least 3 of them and run the photos. The second solution, instead, is based on stereophotogrammetry (4 shots: a stereo-pair and two oblique ones), through which obtain an orthophoto used in the laboratory for CAD representation of the site plan. In this case, it is necessary to materialize other points on the skeleton in correspondence of the major changes in elevation. Following this procedure, the excavation activity may resume after about 30 minutes and the drawing, obtained on the computer, would certainly be more accurate. On July 2008 this solution was adopted at the archaeological site of San Severo (Classe – Ravenna – Italy) (Figure 7) [Aug06]. After about 171 minutes an orthophoto of the burial above was produced, for which the outlines of all the bones of the skeleton were identified and drawn in 43 minutes (Figure 8). A final solution could be to produce quickly the orthophoto and to use as basis directly on the field before continuing the excavation (Figure 6, procedure B).

### 4. The digital 3D survey as standard documentation of the archaeological stratigraphy: an application on the Bronze Age settlement of Mursia (Pantelleria – TP – Italy)

A first experiment was made on the strata of the Bronze Age site of Mursia (Pantelleria – TP – Italy) during the last 2011 excavation season [ACM\*06]. The aim was to obtain a full 3D survey of archaeological deposits of B17 area, corresponding to a square room surrounded by masonry structures in order to take advantage from the three-dimensional data as a useful point to study and understand



**Figure 6:** Scheme showing one of the standard procedures for documentation of inhumation burials (A) and possible alternatives based on the use of PhotoModeler (B, C and D).

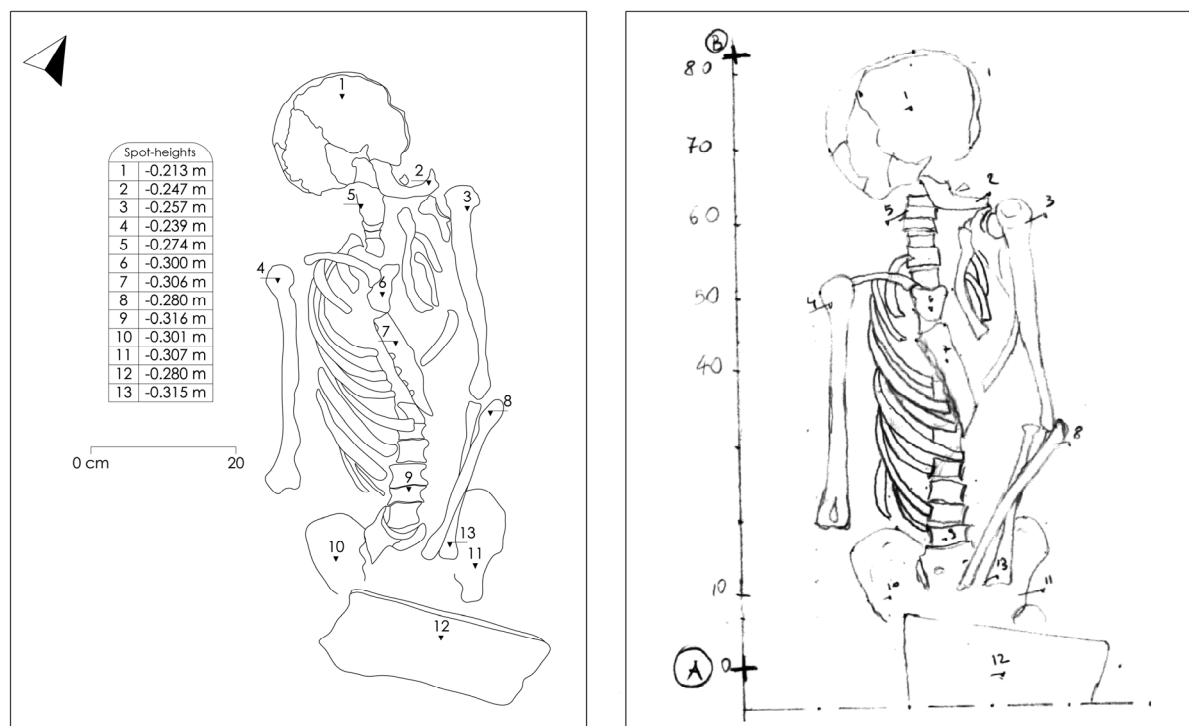


**Figure 7:** To the left: the photo of the burial. To the right: the surface reconstructed from the “point cloud”.

the archaeological records. Having a 3D documentation was considered a high value step on this matter. In a short time, in fact, one can do a volumetric assessment of the stratigraphy, checks of topographic distribution of finds and qualitative analysis of sediment, making it easier to understand the formation of the archaeological deposit. It should be underlined that this experimentation is not an attempt to achieve perfect virtual reconstruction of the site but it is an effort to increase, inside the scheduled action and time of an archaeological mission, the production of

valuable tools for archaeological investigation. So it was necessary to devise a first “operative protocol”, applied to the real case-study of the settlement of Mursia. According with the current consensus of the scientific literature, it was decided to use the stereo-photogrammetry, integrated with total station measurements, as the basic technique of survey. The used setup of tools, experimented previously in 2008, includes: two digital cameras Pentax Optio I-10 (CCD sensor with 12-megapixel), provided with calibration certificate and remote shutter; crafted stereoscopic aluminum arm with graft for tripod; aluminum telescopic pole (extendable up to 10 meters); small discs to materialize photographic control points on surfaces (target points); photogrammetric software Topcon Image Master Pro©; Topcon GPT 3107N total-station; textile panel in light fabric fixed to a pair of wooden scaffolding (3 x 4 meters) used to reduce the intensity of the “shadows” [Fio10].

First of all, photogrammetric survey has been adapted to the timetable of the excavation, trying not to exceed the time range expected from standard documentation. This restrictive point led us into finding a solution to the sunlight problem that creates cast shadows on the objects and that often makes it difficult to clearly read the information on the photos, especially during processing. Therefore, a textile panel (3 x 4 meters size) was made and fixed to a pair of two wooden poles, supported, when needed, by two operators just the time necessary to shoot the photographs. Very important was the coordination work between the sector supervisor and the surveyor, who have combined the requirements imposed by the progression of stratigraphic excavation and update operations of the 3D survey. Thanks to its simplicity and ease of utilization, this

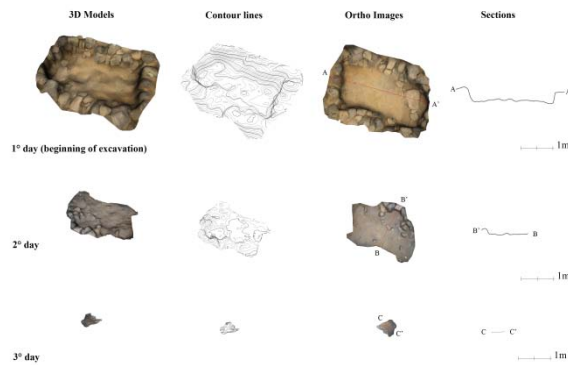


**Figure 8:** To the left: the survey of the skeleton made by CAD starting from orthophoto. To the right: the survey carried out with traditional methods and tools.

system can be used even by non-highly specialized operators. The adopted procedure has proved quite solid, although bound by the above methodological points. In fact, the methods of storage and data processing used do not rule out integration with other data from different instruments and methods of detection. The operational steps can be summarized as follows: A) Field operations: preparation and cleaning of the surface layer or masonry structures; positioning of photographic control point (target); stereo-photogrammetric survey with aluminum rigid pole or free-hand; measurement of the target by total station; B) Laboratory operations: download and management of topographic and photographic data; indexing of the pictures and stereo-pair; elaboration of digital models by the Image Master Pro software; layout and storage of digital documentation; use of digital products during the excavation (maps, sections, overhead view, etc.). Some of previous points do not need specific descriptions because have been, for a long time, part of the common procedures of documentation and under a wide academic attention. However, some of these topics require some attention, because of some innovative features. The use of two cameras (that are triggered simultaneously) to detect an object in stereoscopy has certainly speeded up the acquisition time, also allowing to maintain more precisely the position of cameras especially during the zenithal shots with the pole. This technique produces, for each shot, a couple of photos (stereo-pair) used, at the same time, both

for photographic archive and for processing 3D models. A system of indexing, integrated with the one already in use by the mission and targeted to avoid mismatches between the stereographic pairs has been studied to keep under control this material and to facilitate the retrieval. Each stereo-pair may correspond to a single context or to a collection of contexts. Virtual digital models are produced from the elaboration of one or more pairs, from which it is possible to extract, in a short time, a series of graphic-analytical products implemented and used to study and understand the archaeological contexts. These are divided into four basic types: 3D photorealistic models, geo-referenced orthophotos, contour lines and sections (Figure 9). An important detail of this software and its tools is the possibility to draw, directly on the three-dimensional surface (DEM), themes and characterizations processed as vectorial segments or shape files and imported into any other software platforms such as CAD and GIS. Equally important is the peculiarity of the system to produce this documentation in time to be used during the excavation, greatly expanding the possibilities of interpretation on the field and in the laboratory.

##### **5. Virtual restoration from stereophotogrammetric survey and 3D models: the case of the rock art site of Nag el-Hambulab (Aswan – Egypt)**



**Figure 9:** Series of graphics products extracted from photogrammetric processing of stereo pairs.

In recent years the Aswan – Kom Ombo Archaeological Project (AKAP), lead by the Yale and Bologna Universities, has been studying various selected areas in the Aswan and Kom Ombo region [GC10]. In this concession area many rock art sites have been identified and are in direct danger due to modern economic, agricultural and extractive activities. The NH1 site, located close to the modern settlement of Nag el-Hamdulab, 10 Km North from Aswan, on the western bank of Nile, is one of the most important ones, particularly for the relevant iconography of his drawings. The main panels have been heavily damaged by intentional scratches, reducing the legibility of all figures. Fortunately, various photos taken in the fifties, before the rock art was damaged, have allowed us to operate a virtual restoration of these drawings. We reconstructed a virtual photorealistic model of the main panel in its current condition on which we can then apply the historical photographs, making a sort of virtual restoration. Like that, the original aspect of the rock art drawings has been metrically matched with the texture extracted from the 3D model, created with the software Topcon Image Master Pro (Figure 10). After these elaborations, the new restored model was loaded on a 3D visualisation software (VRML) to appreciate the original splendor and making other observation.

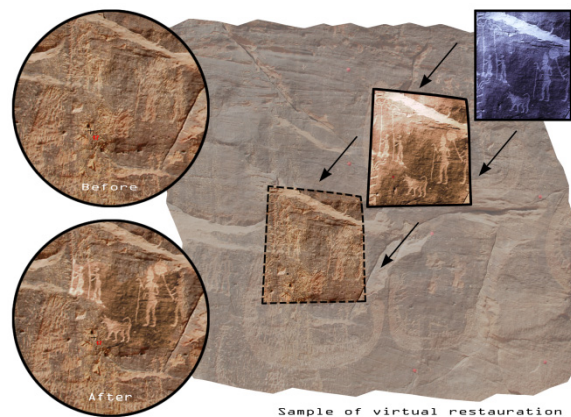
## 6. Conclusions

Plants, sections and elevations are part of normal analytical documentation of each stratigraphic excavation. The manual drawing of these charts follows a set of rules by which one can represent a three-dimensional object on a two-dimensional plane (the sheet). The end result is a scale representation of the object, often based on direct survey and completed by hand. This type of documentation is characterized by a strong element of subjectivity and a consistent supply of formal schematization. Moreover, the manual survey does not allow recording three-dimensional component of layers and archaeological artifacts.

When the graphic registration is made on photomap of a surface excavation, there are two problems: 1) how to retrieve three-dimensional data ignored by monoscopic photogrammetry; 2) how to improve the geometric accuracy of representation when the reality is complex and characterized by a strong three-dimensional morphology.

The need to obtain not only two-dimensional graphical representations, but also three-dimensional (along with the search for greater measurement accuracy and speed of execution) leads us, therefore, to continue experimenting with new tools and methodologies. Thanks to this research some important techniques able to overcome the limitations of manual drafting and monoscopic photogrammetry were identified. In fact, satisfactory results were obtained with photomodelling and stereophotogrammetry in all the case studies discussed (in terms of measurement accuracy and speed of execution), supporting a relatively lower cost compared to other three-dimensional detection systems.

As seen therefore, a strength point of the methodology proposed can be detected in the operational simplicity, that allows a systematic and daily usage. This way, all the usual documentation produced during the excavation (S.U. forms, Material tables, Matrix, etc.) can be connected to the 3D models, leading a real advantage for those who will continue the archaeological investigation. The products obtained through the proposed system, may also become an effective tool to spread and valorize the excavation data. One example is surely the new systems for digital edition (such as 3D PDF), on which it is possible to publish and display interactive three-dimensional models and their information, available and manageable by all users.



**Figure 10:** Digital restoration process of the texture.

## References

- [ABB\*09] Andrews D., Bedford J., Blake B., Bryan P., Cromwell T., Lea R., *Measured and Drawn. Techniques and practice for the metric survey of historic buildings (second edition)*, Swindon, 2009.

- [Aug06] Augenti A. (ed.), *La basilica e il monastero di San Severo a Classe. La storia, gli scavi*, Ravenna, 2006.
- [ACM\*06] Ardesia A., Cattani M., Marrazzi M., Nicoletti F., Secondo M., Tusa S., *Gli scavi nell'abitato dell'età del Bronzo di Mursia, Pantelleria (TP): Relazione preliminare delle campagne 2001-2005*, «Rivista di Scienze Preistoriche», LVI, 2006, pp. 293-367.
- [BM07] Barber D., Mills J., *3D Laser Scanning for Heritage*, Swindon, 2007.
- [BBC\*04] Beraldin J.A., Blais F., Cournoyer L., Godin G., Rioux M., Taylor J., *Active 3D Sensing for Heritage Applications*, in Ausserer K.F., Börner W., Goriany M., Karlhuber-Vöckl L. (eds.), *Enter the Past: the E-way into the Four dimensions of Cultural Heritage CAA 03 Computer Applications and Quantitative Methods in Archaeology*, Proceedings of the 31st Conference, Vienna, April 2003, Oxford, 2004, pp. 340-343.
- [CCDS09] Callieri M., Cignoni P., Dellepiane M., Scopigno R., *Pushing Time-of-Flight Scanners to the Limit*, in Perlingieri C., Pitzalis D. (eds.), *VAST09: The 10th International Symposium on Virtual Reality, Archaeology and Intelligent Cultural Heritage*, St. Julians, Malta, 2009, pp. 85-92.
- [CF06] Campana S., Francovich R. (eds.), *Laser scanner e GPS. Paesaggi archeologici e tecnologie digitali*, Firenze, 2006.
- [De09] De Luca L., *La photomodélisation architecturale. Relevé, modélisation et représentation d'édifices à partir de photographies*, Paris, 2009.
- [DMV10] Dutailly B., Mora P., Vergnieux R., *3D Reconstruction of Archaeological Sites Using Photogrammetry*, in Artusi A., Joly-Parvex M., Lucet G., Ribes A., Pitzalis D. (eds.), *VAST10: The 11th International Symposium on Virtual Reality, Archaeology and Intelligent Cultural Heritage - Short and Project Papers*, Paris, France, 2010, pp. 45-48.
- [Fio10] Fiorini A., *La documentazione tridimensionale dello scavo archeologico nell'abitato dell'Età del Bronzo di Mursia, Pantelleria (TP)*, «IpoTESI di Preistoria», vol. 3, n° 2, 2010, pp. 1-14.
- [Fio09] Fiorini A., *Rilievo archeologico mediante dispositivo scanner laser 3D. Verso una registrazione tridimensionale delle evidenze stratigrafiche: l'edificio 2 - magazzino - nel sito archeologico di Classe*, in Bartolucci D., *Principi di laser scanning 3D. Hardware - metodologie applicative - esempi*, Palermo, 2009, pp. 100-105.
- [Fio08] Fiorini A., *Esperienze di fotomodellazione e stereofotogrammetria archeologica*, in G. Volpe, G. De Felice, M.G. Sibilano (eds.), *L'Informatica e il metodo della stratigrafia*, Atti del Workshop (Foggia, 6-7 giugno 2008), Bari, 2008, pp. 175-186.
- [FA11] Fiorini A., Archetti V., *Fotomodellazione e stereofotogrammetria per la creazione di modelli stratigrafici in archeologia dell'architettura*, «Archeologia e Calcolatori», XXII, in press.
- [GC10] Gatto M.C., Curci A., *Ricerche Archeologiche nella Regione tra Assuan e Kom Ombo, Rapporto Sulle Missioni 2008/2009 e 2010*, in Pirelli R. (ed.), *RISE (Ricerche Italiane e Scavi in Egitto) IV*, Cairo, 2010, pp. 163-176.
- [Jes04] Jess A., *The application of short-range 3D laser scanning for archaeological replica production: The Egyptian tomb of Seti I*, «*The Photogrammetric Record*», 19 (106), pp. 111-127.
- [Mat08] Matthews N.A., *Aerial and Close-Range Photogrammetric Technology: Providing Resource Documentation, Interpretation, and Preservation*, BLM Technical Note 428, September 2008.
- [Mig01] Migliari R. (ed.), *Frontiere del rilievo. Dalla matita alle scansioni 3D*, Roma, 2001.
- [VFS08] Volpe G., De Felice G., Sibilano M.G. (eds.), *L'Informatica e il metodo della stratigrafia*, Atti del Workshop (Foggia, 6-7 giugno 2008), Bari, 2008.