The potential of 3D techniques for Cultural Heritage object documentation

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ABSTRACT

The generation of 3D models of objects has become an important research point in many fields of application like industrial inspection, robotics, navigation and body scanning. Recently the techniques for generating photo-textured 3D digital models have interested also the field of Cultural Heritage, due to their capability to combine high precision metrical information with a qualitative and photographic description of the objects. In fact this kind of product is a fundamental support for documentation, studying and restoration of works of art, until a production of replicas by fast prototyping techniques. Close-range photogrammetric techniques are nowadays more and more frequently used for the generation of precise 3D models. With the advent of automated procedures and fully digital products in the 1990s, it has become easier to use and cheaper, and nowadays a wide range of commercial software is available to calibrate, orient and reconstruct objects from images. This paper presents the complete process for the derivation of a photorealistic 3D model of an important basalt stela (about 70 x 60 x 25 cm) discovered in the archaeological site of Tilmen Höyük, in Turkey, dating back to 2[nd] mill. BC. We will report the modeling performed using passive and active sensors and the comparison of the achieved results.

Keywords: 3D modeling, laser scanner, camera calibration, 3D analysis

1. INTRODUCTION

The field of Cultural Heritage and in particular Archaeology is greatly interested in using the emerging and available new digital techniques and technologies offered by Geomatics. This implies the possibility of obtaining new products not only from the surveying phase but also in the representation and visualization phases, with the aim of having a rigorous and digital description of objects, structures and territory, but also to provide powerful instruments for data analysis and exploration in view of a successive reconstruction and restoration. Data recording must be performed following appropriate methodologies, taking into account (1) the characteristics of each technique either in terms of intrinsic capabilities (precision, accuracy, data dimensionality, etc.) or suitability for mutual integration and (2) the establishment of a common shared database of digital information useful for disparate applications and communities. Such an approach has been for instance followed in several works performed by the authors on archaeological contexts, enabling a multi-scale approach to Cultural Heritage sites, from the surrounding territory to a smaller area of interest or excavations, and finally to single objects [1, 2]. This approach includes normally the use of different techniques or image sensors and platforms, but all the results are as possible georeferenced to a common well established reference system. For this purpose reference points or a reference network must preliminary be defined and surveyed with total stations or spatial geodesy. GPS is also used in kinematic mode for morphological description of areas and surveying of structures. Sometimes GPS is coupled with topographical instruments and aerial or close-range photogrammetry so the results are in any case provided within the same reference frame. Satellite remote sensing imagery, georeferenced as well, is used for mapping purposes, or for thematic interpretation and classification, or merely to provide a background for the site and its surrounding territory visualization. At the site scale, surveying is performed by total stations, terrestrial laser scanning or close-range photogrammetry. Photogrammetry, alone or in connection with laser scanning, add to the capability of an accurate 3D geometric description the richness provided by the radiometric contents. An image, or a set of linked images, can provide very interesting information, either by visual inspection or by automatic recognition, for the analysis of a structure and of its state (e.g. for diagnosis or restoration purposes); the knowledge of a site is greatly facilitated if the means for virtual immersive exploration are provided, using visual or virtual reality techniques, based on photographic data (e.g. QTVR technology) or vector/raster structures (e.g. VRML products). Finally, the study of single objects can be performed using different modeling approaches, depending on the characteristics of the object (size, location, shape, etc) and on the purposes of the work. Frequently digital photogrammetric surveys are an optimal solution because of their characteristics to perform the survey without contact with the object, in a cheap way and in a very short time, therefore without interrupting for a long period an excavation activity. An interesting trend in this sense is the use of non metric digital cameras, carefully calibrated by appropriate algorithms and procedures [3]. Active sensors [4], like laser scanning, are also often used to perform the survey of an object with a very high density of 3D information, and with the possibility to couple the point clouds with their radiometric attributes (e.g. colours) acquired by calibrated (embedded or external) cameras. However the availability of

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a range instrument on a site during the excavation is sometimes unusual, unfair and expensive due to complex logistic problems and the high cost of the instrumentation.

An interesting situation during an archaeological work is when a new find is discovered. The archaeologist acquires some photos of the object, using normally professional photo-cameras, but not calibrated and without any knowledge of the successive modeling problem. If the object is sufficiently small, a 3D mould can be realized in order to study it after the campaign. The mould is then a precise copy of the object in terms of its geometry, but the colour information relies on the photographic data; the datasets are normally uncorrelated among them. The same happens when we dispose of a 3D copy of an object in a museum, and of some images taken by amateur cameras, maybe in the past.

In archaeology, even if a movement towards digital technologies is appearing, the use of 3D digital models for documentation and visualization purposes is rarely applied due to (i) the high “cost” of 3D; (ii) the difficulties of non-experts in achieving easily good 3D models; (iii) the consideration that 3D is mainly an additional “aesthetic” factor; (iv) the difficulty to integrate 3D worlds with other classical 2D data. Currently we can distinguish three main approaches for the recording, documentation and visualization of cultural heritages sites and objects: (1) image-based methods [5]; (2) range-based methods [4, 6]; (3) a combination of image- and range-based methods, as no method by itself can generally satisfy all the recording requirements at the same time. The requirements specified for many applications, including digital archiving or mapping, involve high geometric accuracy, photo-realism of the results and the modeling of the complete details, as well as some automation, low cost, portability and flexibility of the technique. Therefore, selecting the most appropriate 3D modeling technique to satisfy all requirements for a given application is not always an easy task, in particular in archaeological sites.

The paper try to examine the possibilities offered by digital photogrammetry and laser scanning to obtain 3D accurate reconstruction of archaeological objects, with the aim of providing a solution to situations like those above described. A case study is reported, referred to an archaeological activity carried out by a Joint Turkish-Italian project in Turkey.

2. THE TILMEN HÖYÜK SITE AND THE STELA DISCOVERY

The Archaeological Mission of the University of Bologna in Turkey, directed by N. Marchetti, started in 2003 at the ancient town of Tilmen Höyük [7], located in the South-East of the country (Figure 1). The area of investigation is an ancient settlement, located 10 km East of Islahiye town, within Gaziantep province, and dating back to 2nd mill. BC, from the Late Chalcolithic through to the end of the Bronze Age (Figure 2). The archaeological site consists of a 5-hectare mound and lower city with impressive fortifications. The palace complex with a temple, inner and outer strong defense walls surrounding the city, put Tilmen Höyük to an important position from an` archaeological point of view not only in the region, but in the whole country. A multidisciplinary approach for the study of the site and its surrounding area is currently performed; one of the objectives is also to experiment new integrated methods for the remote monitoring of the site and of single structures by different instrumentations and technologies.

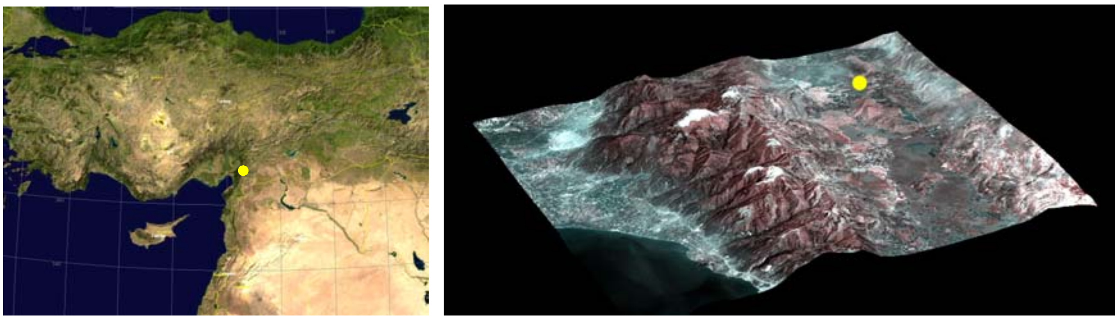

Figure 1: The location of Tilmen Höyük site (Turkey) shown on remote sensing satellite imagery. Left: Landsat mosaic. Right: draping of Aster multispectral bands on the DTM derived from stereo VNIR data.

As far as the surveying and representation processes concerns, with the aim of supporting all the research carried out by the different working groups (archaeological, geophysical, agrarian, etc…), a multi-technique approach was chosen, following the criteria exposed in the previous section. Some preliminary results of the site’s modeling were recently published in [8] while in the next sections we will mainly concentrate on the most important find of the site.

Indeed in the following we will mainly describe the 3D modelling of an important Stela [9] discovered in the cella of Temple M during the 2004 archaeological campaign. This basalt Stela (about 70 x 60 x 25 cm, Figure 3-b) shows the weather god and a high ranking official with rolled edge garment; iconographical study suggests this was possibly the vizier. The Stela has been attributed to the late Old Syrian phase. The irregular surface of the object is characterized by holes and cavities of different size.

Figure 2: Panoramic 360° image near the area where the Stela has been discovered.

3. THE RECONSTRUCTION OF THE STELA 3D MODEL

The Stela discovered in the archaeological site of Tilmen Höyük is one of the most important objects found until now by the archaeological Expedition. The possibility of having a metrically accurate 3D model becomes very important for this kind of extraordinary finds, considering also the fact that often in archaeology the researchers have the opportunity of investigate the original object only for a limited period of time. The choice of the most appropriate 3D modeling technique is, in many cases, limited by the economics and temporal constraints concerning the archaeological mission. In fact it's by now demonstrated that active sensors [4], like for example laser scanner instruments, are able to produce directly and quickly very dense Digital Surface Model (DSM), adapting itself at many different survey conditions. But these instruments are still expensive and not easily portable, considering also the logistic problems of conducting these kind of sensors in archaeological areas or problematic countries. Furthermore digital images are in any case necessary for the object's texture acquisition; therefore it often more convenient, cheap and fast to survey archaeological finds and small sites only with images. Besides this, thanks to recently developed algorithms, it's nowadays possible, by means of photogrammetric methods, the generation of detailed and textured 3D models also using images acquired by relatively cheap cameras [10].

In the following sections, we discuss how photogrammetry and laser scanning can be employed to model the important archaeological find, comparing the two methodologies and the achieved results. The recovered 3D digital model represents an indispensable tool for the documentation, study, preservation, divulgation and restoration, until the production of replicas by rapid prototyping techniques is realized. In our case study the results and the problems connected with the two methodologies are analyzed, especially regarding the data processing phase. As in many archaeological missions is unthinkable to have a high performances active sensor available during the excavations to survey objects, structures or finds, the possibility of creating a faithful copy by means of silicone or resin could solve this problem and postpone the survey operations. Therefore, in order to obviate at the original object lack, during the 2004 campaign, a mould of the upper half of the Stela was produced by means of kneadable silicone rubber from which a gypsum cast was subsequently obtained (Figure 3-a)[b].

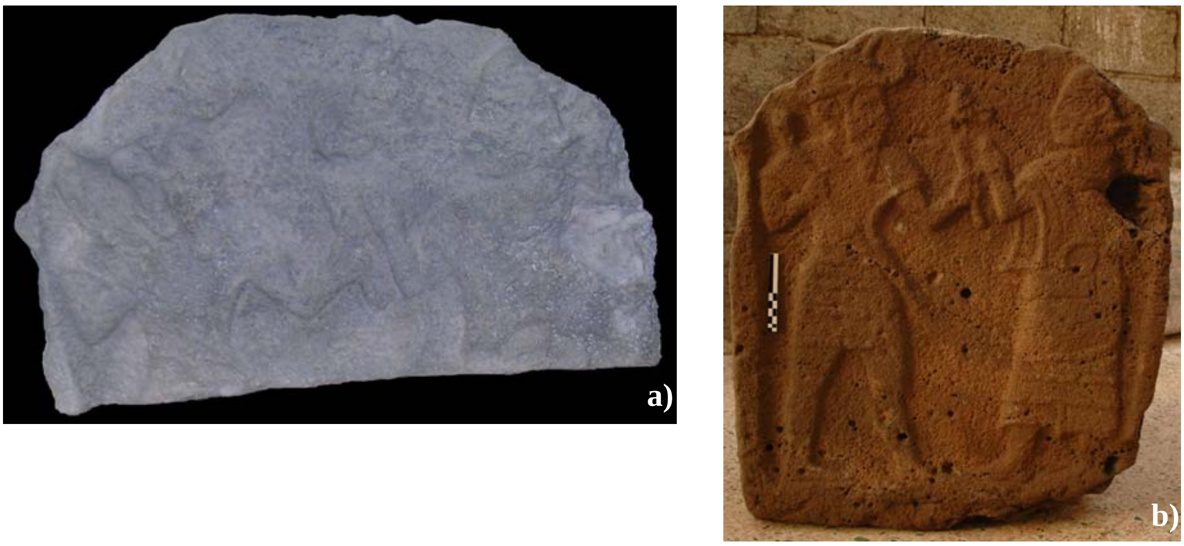

Figure 3: The gypsum cast of the Stela upper part1 (a) and an image of the original archaeological find (b).

Moreover, a small set of digital images of the original find (Figure 3-b), now kept in the Archaeological Museum of Gaziantep (Turkey), was acquired by the archaeologists with an uncalibrated 6 Mpixel Nikon D70 camera.

[b] The 2004 half-reproduction was partial; the entire mould of the Stela was completed in 2005 campaign. The presented study is based on the cast made in 2004, i.e. on the upper part of the entire object; the laser scanning survey of the entire object is currently in course.

In the next sections, the modeling of the Stela from the image data sets and the modeling of the gypsum cast using a laser scanner are presented and compared.

3.1 Image-based modeling

The image-based 3D model of the Stela was performed using two different data sets in parallel. Firstly the amateur images of the original object acquired by the archaeologists on the field, in order to evaluate the possibility of obtaining, even from "not expert user" images, an accurate 3D model. Secondly, a stereo pair of images acquired with a calibrated 8Mpixel digital camera on the whole Stela reproduction. In both cases the extraction of a dense DSM was performed using an in-house surface measurement program [10].

The new consumer digital cameras provide for high resolution images together with lightness, handiness, relatively cheapness and use easiness. But, on the other hand, data processing is still a difficult task, especially if the images are uncalibrated or are acquired under a non-conventional geometrical configuration, or the object is very complex and a dense and detailed reconstruction is required. Nowadays a wide array of software is available to support the generation of image-based 3D model, but a fully automated processing is still a far aim, in particular for the exterior orientation procedure and automatically extraction of a Digital Surface Model (DSM). The user interaction is generally required, to achieve reliable results, due to the objects complexity and generally convergent images. The latter is one of the most crucial problems: indeed nowadays a commercial package specific for terrestrial image able to automatically derive precise and reliable 3D models doesn't exist. As far as the calibration concerns, having an initial guess of the interior parameters, for a correct camera calibration the real important point is a multi-stations favourable network [3] where: (1) photos must be taken with the same focusing condition of the application case; (2) in order to eliminate the high correlation present among some of the inner orientation parameters and increase the precision of the adjustment, a convergent scheme of acquisition including orthogonal rolled images is recommended; (3) to compensate the possible planarity of the employed testfield, the images should be acquired at different distances from the object. Generally no 3D known coordinates are required to perform a complete camera calibration while reference data are required for further accuracy analysis.

For the amateur image data set of the Stela, a 6 Mpixel Nikon D70 camera was used on the field. A full camera calibration could not be performed and the interior parameters had to be recover 'on the job', taking as initial guess the values stored in the EXIF header of the images. Due to the unfair image network (Figure 4), not all the interior camera parameters could be recovered but the final a posteriori standard deviation of the adjustment resulted about 1 pixel.

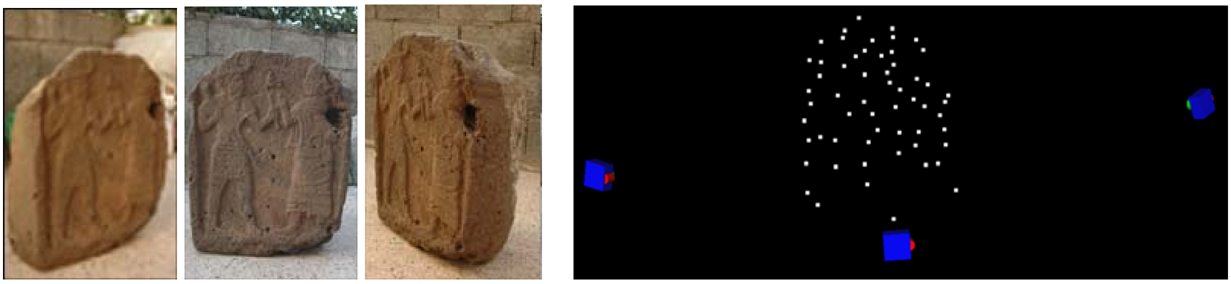

Figure 4: The three widely separated amateur images of the original Stela
and the recovered camera poses with tie points 3D coordinates.

As in 2005 also the lower part of the Stela was reproduced (again in gypsum from a kneadable silicone rubber), for completeness in the documentation, a stereoscopic pair of the complete Stela replica was acquired using the Canon EOS350D 8 Mpixel digital camera (Figure 5), with 22 mm lens and focus at ca 1 m camera-object distance. The camera was pre-calibrated in our lab by means of a photogrammetric self-calibrating bundle adjustment.

Once the cameras are calibrated and oriented, a detailed surface model of the archaeological object can be derived by means of dense image matching algorithm. For this, an in-house surface measurement program developed to match (convergent) close-range images and based on multi-photo geometrically constrained least squares matching was used [10]. The multi-image matching approach was originally developed for the processing of the very high-resolution satellite imagery and afterwards modified to process other image data, such as the traditional aerial photos or close-range images.

Figure 5: The stereoscopic pair of the Stela replica.

The matcher, starting from the known interior and exterior orientation parameters, performs firstly an image pre-processing and generates image pyramids. The images are enhanced combining an adaptive smoothing filter and the Wallis filter, in order to reduce radiometric problems, such as strong bright and dark regions and optimizing the images for subsequent feature extraction and matching. Then the DSM is created by means of a Multiple Primitive Multi-Image (MPM) matching on epipolar images. All available images are matched simultaneously, without having to match all individual stereo-pairs and then merge the results. Primitives like feature points, grid points and edges are extracted and matched using together area-based, feature-based and relational based matching procedures. Moreover, at each pyramid level, a surface model is reconstructed from the matched features and used to constraint the search in the next pyramid level. The algorithm needs some seed points to start the automated DSM generation and they are so far measured manually on stereo models in the areas where big depth discontinuity in the surface are present.

In Figure 6, the 3D models obtained from the two image data sets are shown. In the case of the amateur images (Figure 6, left), the model is not complete at the object border because of an excessive convergence of the images (see also Figure 4). But worth to be observed is that despite the highly convergent triplet, the matcher could process them without great problems and derived a detailed 3D result.

Figure 6: The image-based 3D model of the Stela. Results from the amateur images taken on the field (left, as shaded and colour-shaded model) and using the stereo-pair of the replica (right, as shaded and textured model).

3.2 Laser scanning modeling

As already mentioned, close-range active sensors are quite common and practical in different modeling situations. Moreover the current software for data processing allows to perform in an almost automated way the classical elaboration phases and in particular the scans global alignment, obtaining final residual error less than 100 μm.

The survey of the cast of the upper part of Tilmen Höyük Stela [11] (the scanning of the whole gypsum object is currently undergoing) was performed with a prototype triangulation-based optical laser scanner. The BIRIS sensor has a Twinline Vitana range camera which employs a measuring range sensor developed by the V.I.T. (Visual Information Technology) group of the National Research Council of Canada, in Ottawa. The close-range active device allows acquiring range data with an accuracy of ca 50μm for distances ranging from 30 to 50 cm. In order to acquire the object surface without gaps and holes in the data, the scanning was performed from many different positions around the object; 25 scans were performed at a distance of ca 35 cm, setting the laser parameters in order to reach a point spacing of 1 mm. The alignment of the scans was performed in PolyWorks (InnovMetric) applying an ICP-based global alignment algorithm; the operation has achieved a residual error of 74 μm. The final registered point cloud, after reduction and filtering in the overlapping areas, contained about 2 million points. For the successive photo-texturing of the 3D model of the Stela, RapidForm (Inus Technology) was used. The generated mesh was afterwards decimated to ca 1 million triangles which were then textured with one digital image of the original object, defining corresponding points between the polygonal model and the image. The final 3D (textured) model of the upper part of the Tilmen Höyük Stela is shown in Figure 7.

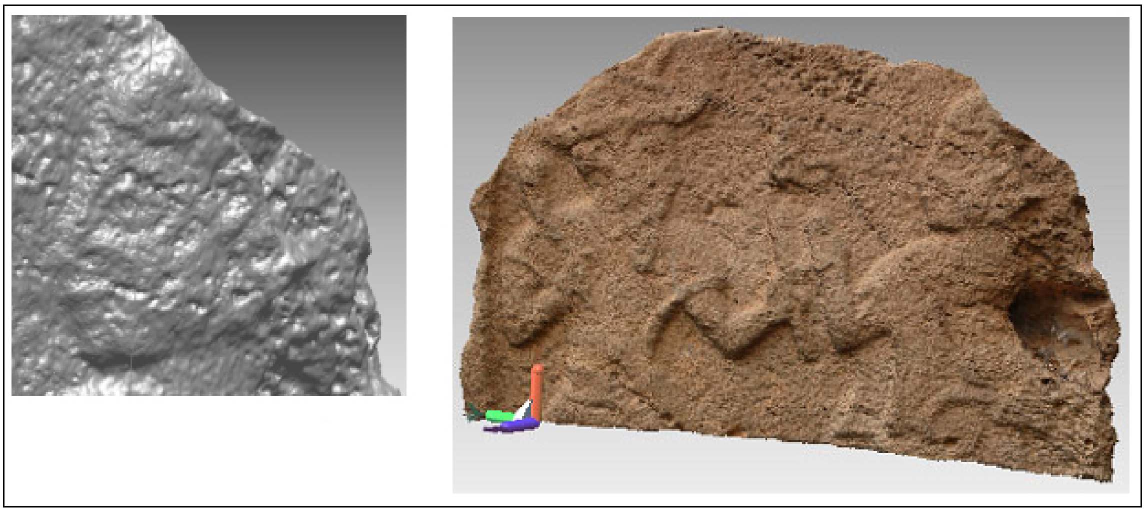

Figure 7: A particular of the shaded model (left) and the textured result (right) of the cast of the upper part of the Stela.

3.3 A comparison between photogrammetry and laser scanner of the upper part of the Stela

In order to evaluate the 3D models achieved with the two modeling approaches, a 3D analysis and comparison of the results was carried out. For this, the laser scanner model was compared with the results obtained from the amateur images, processed as above described, assuming that the gypsum reproduction was as much as consistent with the original archaeological find.

From a first visual analysis, it seems that laser scanning is more suitable for the reconstruction of the little particulars of the object, like for example the little holes of the surface (Figure 8). But it's evident from the results of Figure 6 that photogrammetric 3D modeling, based on dense matching reconstruction and supported by ad-hoc algorithms and image resolution, is able to produce accurate object modeling as well. Some smoothing effects [5] might appear in the final 3D results, due to area-based matching approaches, but newly developed algorithms [10] can partially avoid this and achieve detailed results.

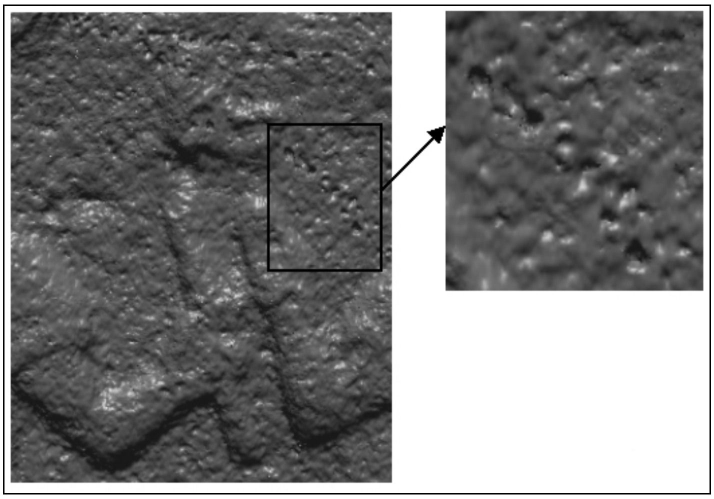

Figure 8: A particular of the laser 3D model with in evidence little characteristics of the surface.

To perform a quantitative comparison, considering the different reference systems of the two products, a global alignment of the two DSMs was performed within RapidForm software using the same principle when aligning two scans. Then the discrepancies between the two shells were analyzed. As shown in Figure 9, the residuals are in the order of 1 mm in the common area and considering that photogrammetry has in our case a theoretical precision on the z-coordinates of about 0.7 mm, the 70% of points are inside this range of acceptability. Points with the greater discrepancies lie mainly on the border of the object.

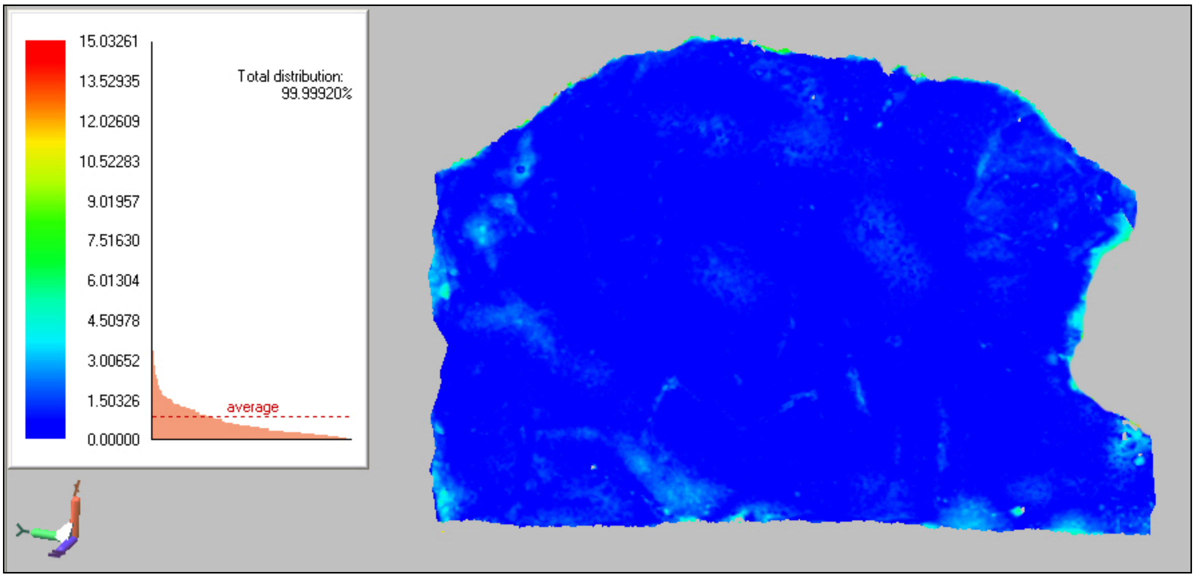

Figure 9: Map of residuals (mm) between laser and photogrammetry (laser – photogrammetry).

4. CONCLUSIONS

Cultural Heritage, and specifically archaeological applications, can benefit nowadays of a growing number of geomatic techniques and solutions for data recording and visualization.

This case study represents a real circumstance where, during the excavations, the archaeologists have acquired a detailed photographic documentation and have realized, by means of a cast, a copy of the surface of an important find. Starting from this information, we have tested the use of laser scanning and photogrammetry in order to build a digital 3D model of the archaeological object. Both approaches produced very satisfactory results and also their visual and quantitative comparisons show that they are really alternative for this kind of applications. Even if the images were not acquired by surveying experts and without metric or calibrated cameras, the derived image-based 3D model contains all the details required for a precise documentation of the find (Figure 10). And also the comparison with the high definition scanned Stela surface model, showed how modern matching algorithms, together with high-resolution images, can really satisfy almost all the modeling requirements with very low costs.

This experiment confirms how the two modeling approaches are sometimes equivalent in 3D object reconstruction. It's evident that the use of the laser scanning directly on the field is not realistic in many campaigns, both for the high cost of the instruments, for the logistic and the practical constraints of archaeological sites. On the other hand it's clear that the use of non-metric cameras for data acquisition makes necessary the adoption of refined specialist procedures for the camera calibration/orientation and for the matching phase, with the employment of software often developed ad-hoc.

Anyway the presented experience has pointed out that nowadays is feasible to derive 3D textured model in digital form also using simple digital cameras and images acquired by non expert surveyors. The achieved 3D results allow for inspection and study, replica and divulgation until when the creation of virtual museums of objects physically kept in the original countries and not easily accessible is realized.

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Figure 10: A closer view of the textured 3D model of the Stela derived from the three highly convergent amateur images.