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Terrestrial laser scanning and close range photogrammetry for 3D archaeological documentation: the Upper Palaeolithic Cave of Parpalló as a case study

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Graphic and metric archaeological documentation is an activity that requires the capture of information from different sources, accurate processing and comprehensive analysis. If monitoring of the state of conservation is required, this task has to be performed before intervention, during and after the completion of the works in a repetitive way.

This paper presents the use of terrestrial laser scanning (TLS) in order to effectively produce, prior to intervention, accurate and high-resolution 3D models of a cave with engravings dating back to the Upper Palaeolithic era. The processing of the TLS data is discussed in detail in order to create digital surface models. The complexity of the cave required the integration of two techniques, TLS and close range photogrammetry to yield not only traditional drawings such as sections and elevations, but also photo-realistic perspective views and visual navigation worlds fully operational in 3D environments. This paper demonstrates the potential of integrating TLS and close range photogrammetry to provide both accurate digital surface models and photo-realistic outputs. This processed data can be used to systematically improve archaeological understanding of complex caves and relief panels of prehistoric art with tiny engravings.

1. Introduction

In this paper we present a case study combining 3D measuring techniques such as terrestrial laser scanning (TLS) and photogrammetry to yield a high-resolution photo-realistic 3D model of Palaeolithic engravings in the interior of the Cave of Parpalló situated on the Iberian Peninsula (Spain). First after the general notes introducing the used techniques, a review of the benefits and drawbacks of TLS and photogrammetry are presented. Then we concentrate on how virtual images can improve the analysis on complex surfaces. Furthermore we continue in showing how to tackle the workflow followed by combining TLS and photogrammetry. After the analysis and combining the data we enter into the discussion of the results, and finally the conclusions are presented.

Traditional techniques to record and document petroglyphs and inscriptions executed in hard surfaces include tracing with (wet) paper and pencils/crayons, free-hand drawing, photography, plaster moulding, latex and wax rubbing. According to Diaz-Andreu et al. (2005) these techniques cannot reproduce the degree of detail and accuracy required by today's researchers and conservators. In fact, they are inherently subjective and limiting, as they represent 3D objects into 2D supports. For some years there has been an increasing demand in the digital documentation of archaeological sites and artefacts. Furthermore, as stated by Robson Brown et al. (2001), the detailed survey of surfaces is an important aspect of archaeological data collection and investigation. In this sense, three-dimensional photo-realistic models allow, among other benefits, to document, manage and analyse the shape and dimension of the represented objects with a high degree of accuracy and resolution, having the potential to revolutionise rock art recording.

Nowadays, three different methodologies are widely used in order to acquire these models: (i) by means of close range photogrammetry; (ii) by means of TLS; (iii) or with a combination of both techniques. These methodologies are based on optical or range 3D data acquisition, are non-invasive, prevent damage of archaeological objects and provide digital documentation and visualization of volumetric geometries. The choice of which method to use depends on the investigated object or area, the user's previous experience and the available budget and time, amongst others (Lambers and Remondino, 2007).

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On the one hand, photogrammetry is a mature technique for the extraction of 3D information from images and its benefits in archaeology are well known. Several works can be found regarding the documentation and map generation of archaeological sites from aerial images, such as the ones presented by Bryan et al. (1999), Bewley (2003), Desmond and Bryan (2003) as well as Lerma et al. (2006). Chandler et al. (2007) present a methodology that is carried out in order to generate elevation models of rock art using close range stereo pairs acquired on-site with consumer-grade digital cameras. On the other hand, laser scanning allows the high-resolution capture of geometric shapes, and thus laser scanning technology stands out as an alternative to the traditional surveying techniques – or at least as a complement. These devices are used in the field of industry for design, development of prototypes or in quality controls, as well as in engineering and architecture for the documentation of plants, buildings or landscapes. Moreover, its wide possibilities have been demonstrated in the registration of archaeological artefacts and sites, architectural buildings and cultural heritage documentation. For instance, Robson Brown et al. (2001) obtain accurate 3D models of a carved rock surface from the Upper Palaeolithic site of Cap Blanc in Southwest France. Diaz-Andreu et al. (2005) record different items of prehistoric rock art such as the stone circle at Castlerigg and a standing stone of Long Meg in Cumbria. Doneus et al. (2008) present a methodology in order to achieve challenging archaeological prospection in vegetated areas by means of multi-pulse full-waveform airborne laser scanning. Entwistle et al. (2009) present a methodology to integrate a high-resolution 3D model of an abandoned settlement site with soil chemical data. Besides, compared to the equipment used on tripods, the hand-held scanners allow in situ documentation in difficult circumstances and sites such as ravines, steep slopes and other vertical, tilted or hanging rock formations (Lönnqvist and Stefanakis, 2009).

In the last few years, many authors have combined both photogrammetry and TLS in different ways (Alshawabkeh and Haala, 2004; Al-kheder et al., 2009; Al-Manasir and Fraser, 2006; Yastikli, 2007). Most of the works on cultural heritage are focused on modelling architectural structures; some of them focus on archaeology. For instance, El-Hakim et al. (2004) present a technique to digitally document aboriginal paintings at the Baiame rock art cave in New South Wales, Australia. Despite all the advantages of 3D recording, its systematic use for documentation and conservation of archaeological objects and sites is still not established. According to Remondino and Campana (2007) this is due to: (i) the high cost of 3D data acquisition; (ii) the difficulties in achieving good 3D models; (iii) the consideration that it is an optional process of interpretation; (iv) the difficulty of integrating 3D data with other kinds of data; (v) the rare use of 3D. We argue that applying both TLS and close range photogrammetry has a great potential in the documentation and analysis of archaeological artefacts and sites. The benefits of having such accurate and 3D models in large scale, might overcome the limited utilization of these digital techniques to improve archaeological workflow at present.

2. Review of technology

This section gives an overview of the employment of the three different solutions, pointing out the potential of combining both close range photogrammetry and TLS for recording and documenting archaeological caves. However, the topic of georeferencing terrestrial laser scanning or photogrammetric data is left outside the scope of this article. A deep analysis can be found in e.g. Schuhmacher and Böhm (2005) and others.

2.1. Close range photogrammetry

Photogrammetry can be described as the science and art of measuring and interpreting imagery in order to reconstruct metrically objects either in 3D or in 2D. Close range photogrammetry usually applies to objects ranging from a few decimetres up to 200 m in size. If the orientation in space of one image is known, every image generates a bundle of rays that can be used to either texture models (standalone mode) or measure objects in space (if more than one image is available and intersect the bundle of rays coming from different pictures).

Nowadays, off-the-shelf digital cameras are relatively inexpensive systems and highly portable, and can be easily calibrated to yield accurate results either before the mission (Huang, 1998; Lerma and Cabrelles, 2007) or after the project by means of on-the-job self-calibration (Dornaika, 2007; Ha and Kang, 2005; Habib et al., 2002; Habed and Boufama, 2008). Apart from the metric aspect which is important, images keep all the information required to derive fully textured 3D models. On the one hand, cameras can be directly handled from the ground for terrestrial surveys; on the other, they can be controlled with wireless technology on air devices with unmanned aerial vehicles (UAV) such as remote-controlled helicopters, kites or balloons. If the distance camera-target is up to 200 m, they can also be mounted on helicopters or airplanes to yield either typical aerial set ups with vertical axis photography or convergent imagery.

The computation of image-based 3D models is usually a task that requires the intervention of expertise operators which provide right measurements on multiple images. There are different approaches according to the number of images: multi-convergent processing, processing of stereo pairs or more rarely single image processing (requiring additional surveying data), as well as different levels of automation (e.g. autonomous, semi-automated and manual).

On the one hand, close range photogrammetry has the benefits of being relatively cheap and easy to set up; the portability of taking mainly the cameras (and tripods) to the different sites is an advantage that makes it appropriate for recording a large number of objects and sites. On the other hand, limitations of this technology are the lack of fully automatic solutions that yield satisfactory results (mainly when dealing with textureless imagery). Furthermore, stereoscopic plotting requires expertise operators; many operators can measure well homologous features on multiple monoscopic images but not stereo pairs.

Old photogrammetric approaches would require devices that provide metric data such as metric cameras and photogrammetric scanners (for analogue film sampling). At present, off-the-shelf equipment such as cameras and scanners can be used and calibrated accordingly, regardless of whether they have been properly calibrated or not (although accurate results might only be expected if the devices are fully calibrated). In any case, the knowledge of the exterior orientation parameters, position and attitude of the camera in the object coordinate system is required, as well as the interior orientation parameters (focal length, principal point coordinates and distortion parameters). Collinearity equations establish the functional and stochastic relationship between the unknown parameters and the observations, which are homologous points registered in two or more images (Wang and Clarke, 2001). The complete photogrammetric workflow to derive metric and reliable information from imagery consists of (Remondino and El-Hakim, 2006): (i) design, i.e. sensor and network geometry, (ii) 3D measurements, (iii) structuring and modelling, (iv) texture mapping and visualization. Nowadays, different commercial packages are able to perform these tasks. They allow, after the tie point measurement and bundle adjustment phase, to obtain sensor calibration and orientation data, 3D object point coordinates and wireframe or textured 3D models.

2.2. Terrestrial laser scanning (TLS)

Laser scanning enables a large quantity of three-dimensional measurements to be collected in a short time. It generates a point cloud in a local coordinate system with intensity values; additional information such as RGB values is usually provided by internal or external digital cameras. While the point cloud generated by laser scanning may be useful on its own, it is usually only a means to an end. Laser scanning is generally used to record surface information in order to generate 2D sections, profiles and plans, and 3D models. Laser scanners can operate from the ground or integrated into an airplane. The former is referred to as terrestrial laser scanning (TLS) whereas the latter is referred to as airborne laser scanning or LiDAR, although this latter term applies to a particular principle of operation which includes laser scanners used from the ground (English Heritage, 2007).

TLS might be classified according to its range of measurements or its principle of operation: triangulation, time-of-flight or phase-based. In the first case, the device shines a laser pattern onto the subject and exploits a camera to look for the location of the laser's projection onto the object. In the second case, scanners make use of laser pulses to measure a time frame between two events (the returned pulses). The latter principle is also a time-based measuring principle, but it modulates the power of the laser beam, thus measuring the phase difference between the sent and received waveforms (Lerma García et al., 2008).

As mentioned above, some scanners are capable of capturing the colour of measured points, resulting in point clouds much more representative of the scanned object. A rough 3D coloured model from these point clouds can be derived by taking for every triangle the colour of its vertices. This involves the generation of textured models within a resolution of the order of the size of the triangles. Other scanners include a digital camera directly referenced with respect to the point cloud, which is used to obtain colour from the scanner. Nevertheless, the main drawback of these integrated cameras is their low radiometric and geometric resolutions, as well as the non-parallax free colour values they yield for close range measurements.

Despite the many capabilities of this technology to document archaeological data, certain other aspects should be considered, as laser scanning will not provide a solution to all recording tasks. For instance, it does not provide unlimited geometric accuracy and completeness over objects and landscapes of all sizes – Boehler et al. (2003) give a review of laser scanner accuracies. Scanning might also take a long time to achieve the required quality level, being less versatile than a camera, which records a scene in a matter of seconds. Moreover, being time consuming, along with cost, transportation problems and the complexity of the related data management, often leads to serious issues of practicality in some archaeological sites (English Heritage, 2007; Remondino and Campana, 2007). Scanners also have minimum and maximum ranges over which they can operate. These ranges depend on the manufacturer, and thus the selected device is crucial to properly record the studied site and/or object. All these features make it necessary to carefully plan the surveying process beforehand – a complete guide of TLS theory and practice is given for instance in Lerma García et al. (2008).

2.3. Combining TLS and close range photogrammetry

Knowing the potential benefits of the techniques described above, it is foreseeable that a proper combination of both will lead to even better textured 3D models, i.e. more accurate, with higher resolution and able to more easily complete complex shapes. Boehler and Marbs (2004) discuss the advantages and disadvantages of close range photogrammetry and TLS methods. They find that the former is the best solution when an object can be described predominantly by point or line based structures. On the other hand, the latter is more appropriate when very complex and irregular objects like sculptures, reliefs or other types of archaeological finds with uneven surfaces are to be documented. Finally they state that, in many cases, a combination of laser scanning and photogrammetric processing is the best solution. Furthermore, both technologies should be combined when the characteristics of the study area are complex and with large dimensions (Remondino and Campana, 2007), or when it is possible to find objects or artefacts of varying nature.

3. Case study: the Cave of Parpalló

3.1. Site description

La Cova del Parpalló on the Iberian Peninsula (Spain) is one of the most important international Palaeolithic caves sites, encompassing a part of the whole series of the portable art found in the Mediterranean area. It was granted the status of the World Heritage Site by UNESCO in 1998. The cave is situated near of the town of Gandia on the eastern shore of Spain in the province of Valencia (Fig. 1).

The cave has been known since the mid-nineteenth century, but the first excavations led by Luis Pericot started in 1929 at the site.

Access to the cave (Fig. 2) is through ca. 14 m high by 3 m wide hole, which falls ca. 3.5 m to reach the main room, an irregular 12×4 m floor area an a roof reaching the eight of 17 m.

According to Villaverde et al. (1998) it is important to note that the earliest portable art in Mediterranean Spain is associated with the Upper Palaeolithic Gravettian occupations of Parpalló and Malladetes. The sites further constitute a relevant collection of portable art representing the Solutrean and Magdalenian phases of the Upper Palaeolithic period. The collections of the portable art from both of these sites comprise a significant number of limestone plaques, painted and carved with zoomorphic or, more habitually, abstract images. These designs illustrate the styles that are traditionally associated with different stages of the Upper Palaeolithic art. The Cave of Parpalló itself has provided more than 5600 carved and painted plaques, embedded in an archaeological sequence that covers a period of more than 10,000 years. Apart from the chronology based on the stylistic developments discernable in the art of the plaques, this archaeological sequence provides an important chronological point of reference to the whole Upper Palaeolithic rock art in Europe in general. Recently, for example, parietal art was discovered at the wall of the bottom of the cave, with an engraved equid and non-figurative lines, and based on the archaeological levels excavated by Pericot it was possible to date these news finds of rock art. A more detailed discussion of Parpalló role in the context of the Palaeolithic art of the Iberian Peninsula can be found in Bicho et al. (2007).

3.2. Planning and data acquisition

The TLS data acquisition at the Parpalló Cave site was conducted with the medium-range phase-based scanner FARO LS 880HE in late June 2007 (Fig. 3). The maximum range of this device is 70 m, with a field angle of 360° (horizontal) and 320° (vertical). This scanner is characterized by its high resolution (up to 3 mm at 10 m distance), field angle and speed.

In projects involving laser scanning technology, the positions of the scanner must be carefully planned to ensure full coverage of the

Fig. 1. Location of the three main Palaeolithic cave sites on the Iberian Peninsula around Gandia.

3D object, appropriate resolution and required accuracy. For this project, a total of sixteen scans from fourteen different positions were acquired (Fig. 4). In particular, two scans were set up out of the cave to collect its exterior walls, five on the main cavity and seven on the West-oriented gallery (Fig. 5). The mean sampling distance for the scanning area was 5 mm in average for each scan. Additionally, two high-resolution scans with a sampling distance of 2 mm were acquired in the area where the engravings are located. The volume of laser scanning raw data was approximately 123 million points.

Likewise, medium resolution images of the whole cave were shot. The camera used was an in-house calibrated digital Canon EOS D60, resolution 3072 × 2048 pixels, and Sigma 15–30 mm wide-angle lens; only the shortest focal length was used. Fig. 6 displays two single shots of the complex cave taken from the inside.

3.3. Methodology

The approach used to obtain a high-resolution photo-realistic 3D model of the Palaeolithic engraving combining terrestrial laser scanning and close range photogrammetry can be summarised in the following steps (Fig. 7):

1. Point cloud pre-processing. The purpose of this step is basically to filter out the raw data delivered by the scanner, deleting gross errors and isolated points.
2. Point cloud processing. First, point clouds are registered by means of artificial targets provided by the manufacturer (in our case white spheres). This process is also known as alignment or consolidation, and is carried out in order to have all the scans in a single and common coordinate system.
3. Meshing of the 3D point clouds by means of Delaunay triangulation. The output is a surface model of the scene.
4. Image processing. In this step, images are corrected from distortion and oriented to the referenced point clouds (vid. Section 3.3.3).

Fig. 2. Entrance to *la Cova del Parpalló*.

Fig. 3. Data acquisition in *la Cova del Parpalló*.

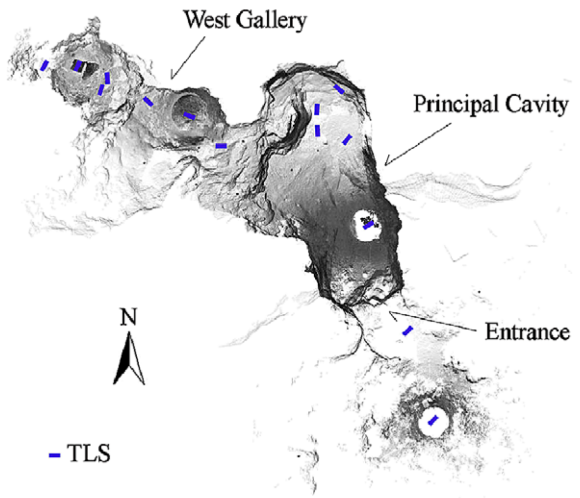

Fig. 4. Plan view of *la Cova del Parpalló* with the fourteen terrestrial laser scanner positions (rectangles).

5. Model texture. For each of the model triangles, the patch of image that best fits the triangle (usually the image whose optical axis is more perpendicular) is selected. This process additionally requires an exhaustive visibility analysis (vid. Section 3.3.4).

Another important step that might follow the aforementioned Point 3 is either profiling or sectioning the digital surface model with different cutting planes, mainly one horizontal plane and one or two vertical planes parallel to the coordinate system.

Point 3 onwards is integrated in the FotoGIFLE software, a home made software developed by the Photogrammetry and Laser Scanning Research Group (GIFLE, 2008) at the Polytechnic University of Valencia.

3.3.1. *Point cloud processing*

The point cloud processing phase begins with the referencing to a single object coordinate system (XYZ) of the filtered raw data captured in the local coordinate system of the TLS. From each station, a unique local coordinate system is set up. Therefore, after the registration step, all the local coordinate systems will be transformed into one (most usually known as master) selected coordinate system. For that purpose, artificial spheres (that act as tie points) have to be placed around the 3D space, trying to occupy the maximum volume. Based on these, it is possible to make a least squares adjustment for all the scans.

Fig. 5. 3D view of point clouds collected in *la Cova del Parpalló*.

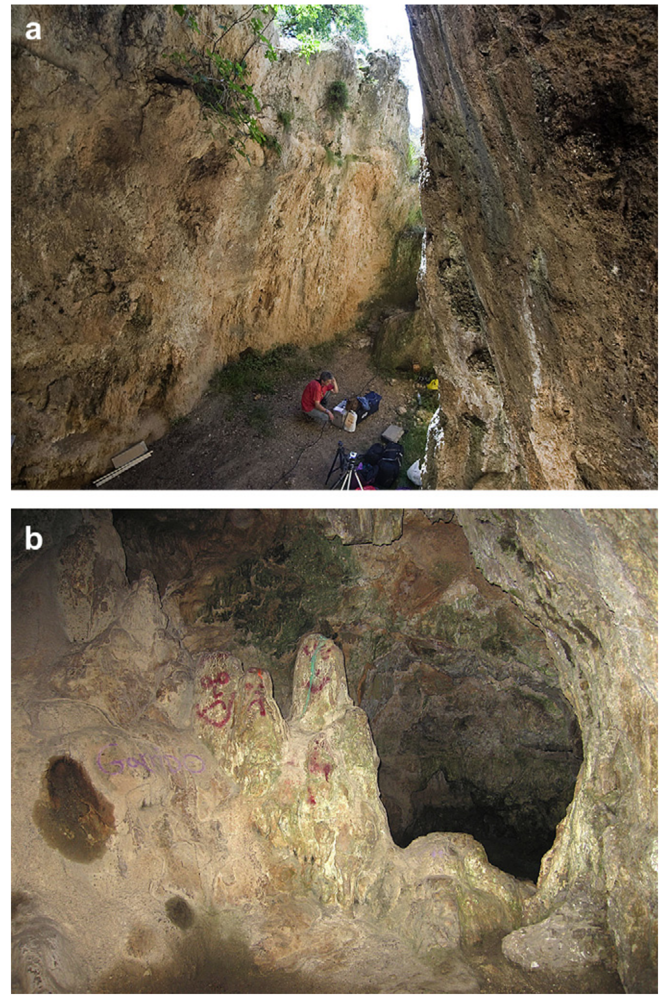

Fig. 6. Pictures pointing: a) Eastwards to the main gallery; and b) Westwards to the Western gallery, with modern graffiti.

Up to this point, processing and edit was performed with FARO Scene software supplied by the manufacturer of the scanner.

Once the point cloud is registered, the whole set of point clouds is oriented to North by means of a digital compass and moved to the coordinates (100, 100, 0) for convenience, in order to facilitate the reading and generation of plans without negative values in planimetry. However, the height origin was set to fit to the level of Luis Pericot's origin of the excavations carried out in 1929. Thus, all the metadata of the data and artefacts discovered, recorded and documented after that period can be virtually placed back in space.

The next step consists of data cleaning for information outside the cave. For this purpose, points that did not belong to the cave such as scaffolding and vegetation were filtered out and eliminated by hand.

Finally, the point clouds are decimated with the help of mathematical algorithms in order to remove redundancies in overlapping areas. In our case, the point cloud was decimated to 15 mm for the whole cave and 2 mm for the close-up.

3.3.2. *Meshing*

This step involves data triangulation to derive a 3D triangular mesh. Alternatively, meshing can also be achieved by quadrangles. In order to avoid suffering from insufficient computer memory, the

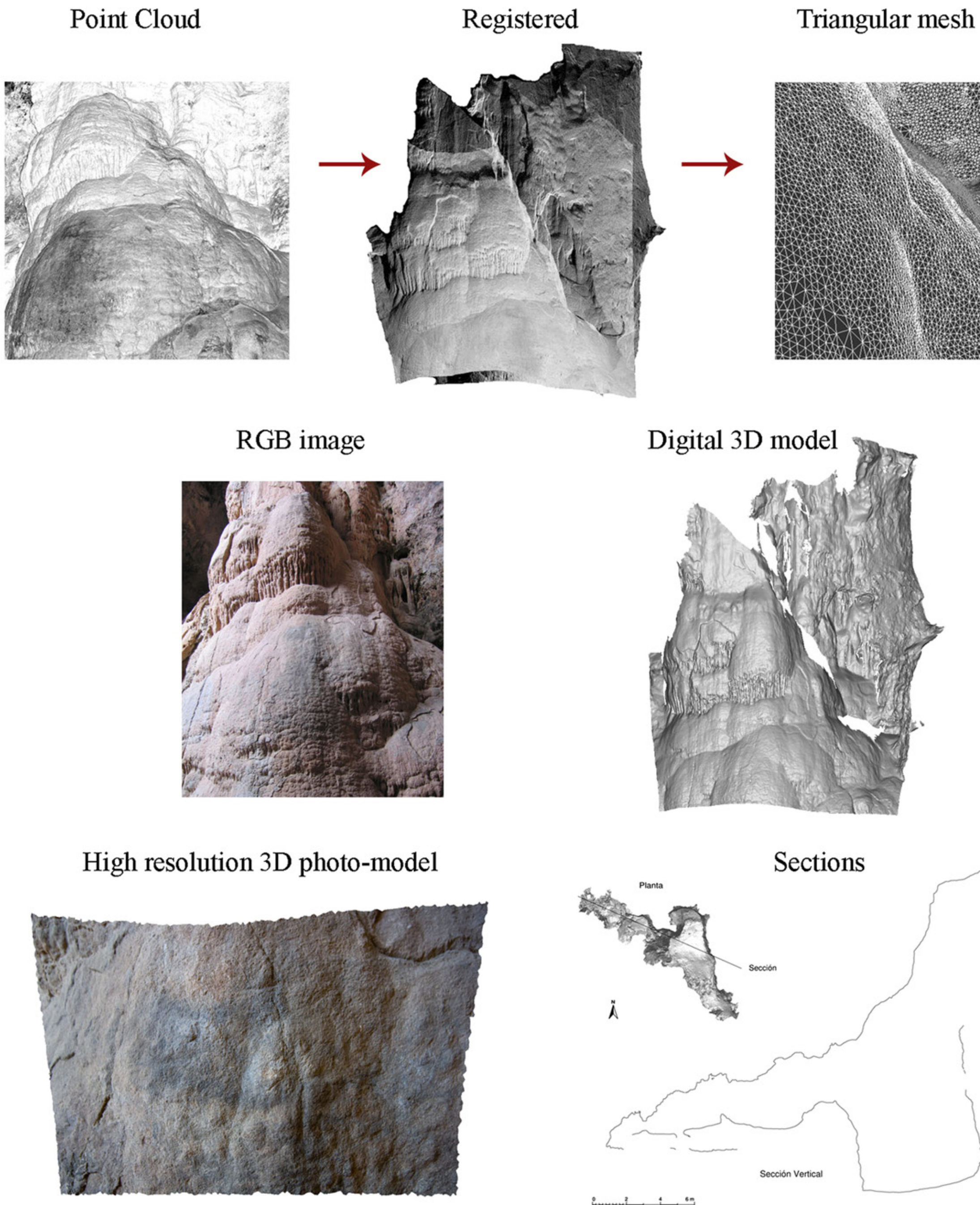

Fig. 7. Summary of steps combining TLS and photogrammetry in *la Cova del Parpalló*.

referenced and decimated point clouds are divided into different levels (in our case, one and half meters in height), and triangulated separately. After triangulation, topological errors are eliminated, including either triangles that cross each other or more than two triangles that share the same side. Once the triangulations have been refined, the previous registration is optimized with the ICP (Iterative Closest Point) method (Besl and McKay, 1992; Chen and Medioni, 1992) and partial models are joined.

Furthermore, editing includes filling up a number of small hidden areas in order to overcome this awkward issue and reduce their number. The result is a full 3D model. In our case, the whole cave consisted of 7.5 million triangles with an average precision better than 1 cm, whereas the high-resolution 3D model of the rock engraving kept one million triangles.

3.3.3. Image processing

The geometric correction of the input imagery can be carried out before determining the exterior orientation parameters if the camera is calibrated, i.e. the interior orientation parameters are accurately known. Otherwise, the determination of the interior orientation parameters, as well as the exterior orientation parameters (that allow the referencing) are obtained altogether by means of either bundle-block adjustment (in case of calibrated camera) or self-calibration bundle-block adjustment (in case of non-metric camera). In either case, image measurement of control points is selected from the TLS point cloud.

3.3.4. Model texture

According to Dorffner and Forkert (1998), a 3D photo-model is an object model where the texture information is taken from images. It consists of two parts: (i) the 3D model itself, and (ii) the textured patches that are projected onto the triangles (or quadrangles). After the processing step the external orientation of the images is known, and the relationship between the object space (model) and the image space (picture) can be mathematically determined. The visibility analysis should be performed to detect dead or shadowed areas and to determine which triangles are intersected by the rays coming from the projection centre and passing through the pixel image. The other way round, as each triangle can only be textured once and that texture corresponds to the shortest distance image-triangle, if the bundle of rays effectively intersects the mesh more than once, all but the shortest triangles cannot be textured from that particular image. Thus, the texture for those parts of the mesh should come from other images (if available). Ultimately, all visible raster points are transformed into the image matrix of the original image.

Our visibility analysis implementation makes use of the ZI-buffer approach, as described by Amhar et al. (1998) and particularized by Biosca Taronger et al. (2007). For the performance of this small target area, three photographs were used to give texture to the portion of the 3D model where the engraving is located: two images taken from a distance to the object of 2.5 m (approximately), and one close-up image taken 45 cm away upon a scaffold. In Fig. 8 different views of a fragment of the textured model are shown, where an engraving representing the figure of a horse can be appreciated. The resolution of the close-up photo-realistic model is approximately 0.23 mm.

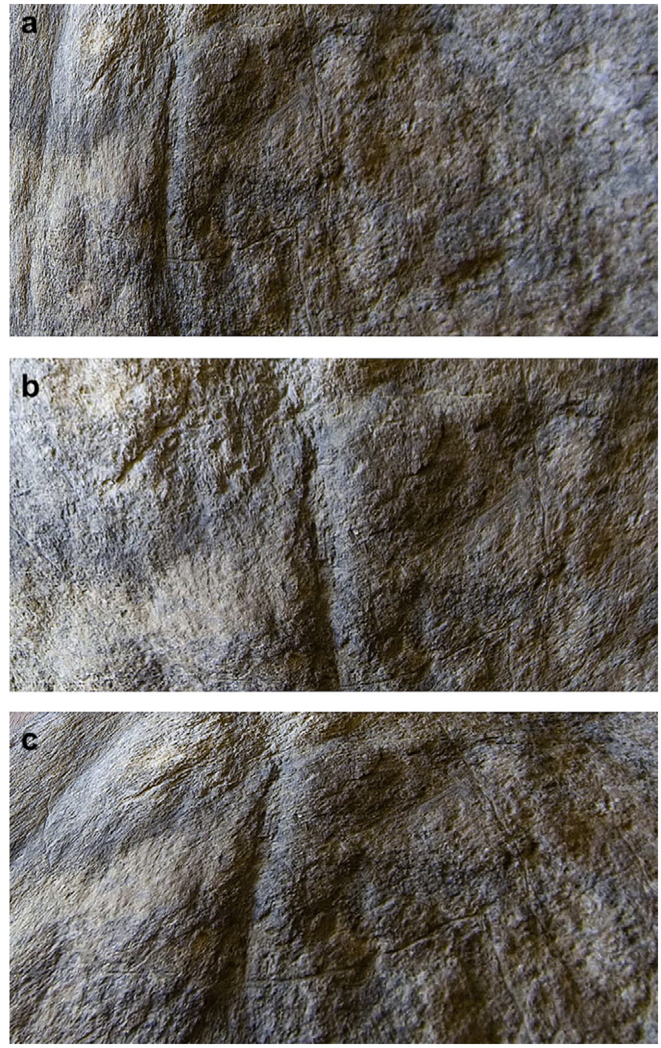

Fig. 8. Detail of the generated 3D photo-model seen from different points of view: a) Front side; b) Bottom; c) Up.

3.3.5. Storage

After generating both the 3D models and the photo-models from TLS or close range photogrammetry, data should be stored in digital form at maximum resolution without losing texture information and keeping also maximum spatial resolution. It is important to save on different media not only the final deliveries and products but also the original raw data without compression. This allows manipulation and editing of data at any time in order to perform different studies without the need to return to the site.

As contemporary software is neither ready to process huge data sets of point clouds nor meshes, operational problems might occur if the TLS data are not divided beforehand. It is recommended to export the data into different formats including also the metadata of the whole project. Proprietary formats are good but public formats are better to guarantee performance and integrity. A good example of public file format for the interchange of 3D point could data is the LASer (LAS) file format (ASPRS Standards Committee, 2009).

4. Discussion

Before the documentation carried out by our team, the available data regarding the topography of the Cave of Parpalló consisted of a hand-drawn 2D plan of 1:200 in scale with the indications of rock materials and dating back to 1988 (derived by J. Fernández Peris and R. Giménez in Aura, 1995) as well as some cross-sections drawings available in scale of 1:400. This information reflected partly the complexity of the cave, and the metrics were very poor when compared with the data provided with the TLS survey.

From now on, the way conservation specialists (archaeologists, cultural heritage conservators, etc.) document and analyse panels will improve with the present 3D data. On the one hand, one of the great advantages of having such a high-resolution and photo-realistic three-dimensional model of an object (specifically this engraving) is the ability to visualize, plot, study and extract easily 2D and 3D information from various points of view and at different scales. Once one perspective is selected, image files such as those presented in Fig. 8 can be instantaneously generated. As well, particularized sections and visualizations can help to characterize the morphology of the engravings, without distortions originating from projecting non-planar 3D information in 2D views. Therefore, the true geometry of the engravings can be derived in real magnitude.

On the other hand, horizontal and vertical sections of the whole cave can be generated (in our case in the sequence of every 5 cm and 25 cm, respectively), in order to constitute a rigorous archive of the metrics of the cave. Last but not least, plans of the cave displaying differences in elevated areas in a varied spectrum of colours, such as top views and bottom views can be easily provided to monitor interventions. Fig. 9 displays how the cave presently looks like.

The principal benefit the photo-realistic models provide over digital images is the chance to manipulate immediately information in 3D. An image only contains 2D data, and this restricts the way data can be used. For instance, a photo-model can be scaled and rotated in order to locate the optimum point of view from

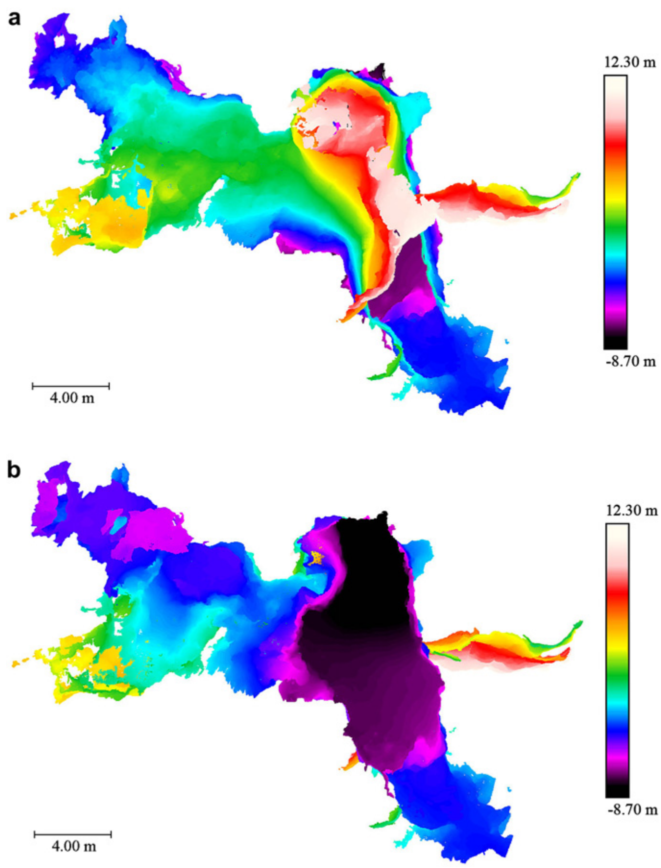

Fig. 9. Elevation plan of the cave: a) Top view; b) Bottom view.

which a studied detail is better appreciated (recall Fig. 8); this would be impossible with a unique 2D image and rarely possible with a bunch of imagery. Indeed, digital 3D information is very valuable and allows the derivation of additional data. This detailed documentation will help to fix future interventions inside the cave.

5. Conclusion

This article demonstrates how effectively the combination of laser scanning and terrestrial photogrammetry ensures a solution to generate 3D models of high photo-realistic quality and the benefits this can provide for documenting complex archaeological sites.

The Cave of Parpalló, one of the most important Palaeolithic sites located in the Mediterranean area of the Iberian Peninsula, was accurately documented. All the interior and parts of the exterior (the entrance) of the cave were scanned. Additionally, a close-up of one parietal engraving was scanned and images were also taken with a conventional digital camera, and merged together following a photogrammetric approach. The study site was accurately documented and high-resolution, high-accuracy 2D and 3D data was derived. A comparison with previous existing plans of its topography in paper format in 2D revealed the advantages of the approach presented here, which offers the possibility of quickly achieving volumetric analysis and photo-models, amongst other benefits.

Therefore, the availability of metric and graphic surveys of archaeological heritage sites, combined with historical, archaeological, paleontological or biological studies guarantees: first the establishment of reliable scientific heritage archives; second the legacy of the transmission of knowledge of our heritage to future generations; and third effective interventions based on multidisciplinary studies.

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