

HIGH RESOLUTION 3D RECORDING AND MODELLING OF THE BRONZE AGE CAVE “LES FRAUX” IN PERIGORD (FRANCE)

P. Grussenmeyer^{a,*}, T. Landes^a, E. Alby^a, L. Carozza^b

^a The Image Sciences, Computer Sciences and Remote Sensing Laboratory

LSIIT-TRIO UMR 7005, Strasbourg, France

(pierre.grussenmeyer, tania.landes, emmanuel.alby)@insa-strasbourg.fr

^b Environmental Geography Laboratory- GEODE UMR 5602, Toulouse, France - carozza@univ-tlse2.fr

Commission V, WG V/2

KEY WORDS: Documentation, Archaeology, Caves, Photogrammetry, Close Range, TLS, 3D Modelling, visualization, PDF-3D

ABSTRACT:

The Bronze Age cave “Les Fraux” at Saint-Martin-de-Fressengeas (Dordogne, France) has been discovered in 1989. This site made of a network of galleries of several hundred meters, is a field of investigation for several researchers. This paper will focus on three-dimensional contact free measurement techniques for a full 3D-documentation of the structural elements of the cave with some focus on cave art details. In this cave, most of the art is etched in the clay and follows linear, schematic and geometric designs. There are indeed several manmade depictions on the walls and other valuable remains of activity all around the cave.

For the archaeologists, the documentation and recording started in 2008 should:

- contribute to the accurate indexing of the surveys and images of the remains and collections as well as structural elements and sculptures;

- guarantee the indexing compatibility of the data between the different groups of researchers involved in the excavation;

- ensure the georeferencing of any type of object in the different parts of the cave.

Different techniques based on Terrestrial Laser Scanning (FARO Photon 80), Digital Photogrammetry (CANON EOS 5D images) and Spatial Imaging System (Trimble VX) have been used. The aim of the documentation work is to generate a geometric and photorealistic 3D model from the combination of point clouds and photogrammetric images, for both visualization and accurate documentation purposes. The underground tunnels of the cave are linked to the above terrain with surveying techniques for an accurate georeferencing. The workflow from the raw data to the final PDF-3D model will be discussed. Emphasis will also be given to the deliverables, since the huge amount of data is not directly usable by the archaeologists.

1. CONTEXT

This paper deals with 3D reconstruction and visualization of a complex archaeological site. Our field of interest is the Bronze Age cave “Les Fraux” (1300 BC) located at Saint-Martin-de-Fressengeas (Dordogne, France). This cave has been discovered in 1989 after the collapse of an artificial lake, allowing access to a complex underground network never visited in the last 3000 years. Several researches are bringing together different specialists in charge of surveying and documentation, excavations, epigraphy, magnetic measurements in this site. Laurent Carozza is managing this archaeological project in France.

Most of the art in the cave is etched in the clay and follows linear, schematic and geometric designs. There are several manmade depictions on the walls and other valuable remains of activities all around. This site, made of a network of galleries of several hundred meters, is a fantastic field of investigation for the researchers.

Advances in Terrestrial Laser Scanning (TLS), as well as the performance of Imaging Systems are rapidly developing, so that a huge amount of data is usually recorded in such a project (Grussenmeyer & Hanke, 2010). The overall recording of the cave (Figure 1) is one of the main topics, since it will ensure the georeferencing of any other operation. In this context,

techniques allowing three-dimensional contact free measurements have been performed for the 3D-documentation of the whole structural elements and archaeological aspects of the cave.

2. AIM OF THE DOCUMENTATION

For the archaeologists, the documentation and recording work (started in 2008) shall contribute to the accurate indexing and georeferencing of the whole set of surveys and images of the remains and collections as well as structural elements and relief drawings acquired in the different parts of the cave. Furthermore, another purpose of the recording is to deliver data and models in formats that can be handled by most of the partners involved.

The cave is linked to the above terrain thanks to surveying techniques, allowing accurate georeferencing in the French Geodetic Reference System. There are several constraints for the recording process, since the original entrance of the cave is unknown at this step of the research. The access for the researchers and their material to the underground tunnels of the cave is limited to a narrow and uncomfortable gallery. Due to several archaeological remains all around the cave, the movements in the cave are restricted along a path designed by the head of the project. Fixed reference points can only be

* Corresponding author.

marked on this path; any other marking is forbidden. Moreover, no lighting is available in the cave for preservation purposes: only cold lamps, high performance LED lamps, flashes and special devices can be used. These conditions prevent the mounting of a camera on the Terrestrial Laser Scanner.

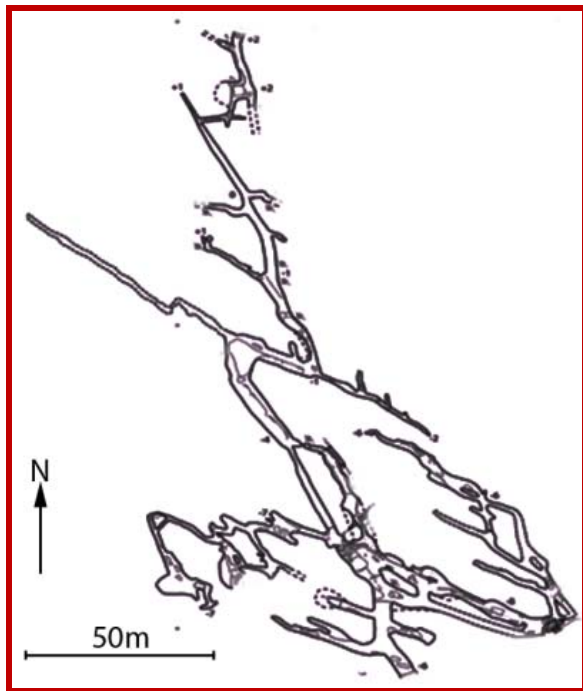


Figure 1. Map of the cave

As usual in documentation of Cultural Heritage, the recording techniques (Patias *et al.*, 2008) are based on the combination of Terrestrial Laser Scanning and Digital Photogrammetry. The aim of the documentation work is to generate a geometric and photorealistic 3D model from the combination of point clouds and photogrammetric images, for both visualization and accurate documentation purposes. The processing, from the raw data to the final PDF-3D models, is a hard and time-consuming task.

3. RELATED WORK

Over the last decade, the number of historical and archaeological objects recorded using innovative 3D surveying techniques has significantly increased. As reported in (Schaich, 2007), historical monuments and items, ranging from huge sections of terrain down to the smallest artefact, can be reproduced with such accuracy and to such a high level of realism that documentation of this kind is extremely useful for archaeologists, conservators and architectural historians. The few projects concerning caves systematically combine terrestrial laser scanning technique and close range photogrammetry (El-Hakim *et al.*, 2004; Fryer *et al.*, 2005; Lerma *et al.*, 2009; Gonzalez-Aguilera *et al.*, 2009). The photography is sometimes used, but only to complete the point cloud with texture (El-Hakim *et al.*, 2004), or as an alternative to TLS. In (El-Hakim *et al.*, 2004), a laser scanner was used combined with digital photography to produce a realistic 3-D model of the Baime cave. Later, (Fryer *et al.*, 2005), tried to model the same cave using digital photography and automated image correlation software to produce a DEM and orthophotography. Both methodologies led to similar products with similar accuracies in the area covered by the pictograph.

Away from the pictograph, the authors observed situations where image correlation will simply not work, at all due to the spectral texture of the cave walls.

The complexity of the Upper Palaeolithic Cave of Parpalló cave also required the integration of both techniques, i.e. TLS and close range photogrammetry. The combination of these techniques not only yielded to traditional drawings such as sections and elevations, but also photo-realistic perspective views and visual navigation worlds in 3D environments (Lerma *et al.*, 2009).

The main problem encountered in the 3D representation of caves is the detailed and photo-realistic texturing of its walls. A manual detection of common points in the 3D model and in the photography used as texture might be a solution in the area of building texturing. But regarding the upper surface of the walls, it is more difficult, since common points are rarely identifiable. (Zhang *et al.*, 2006) propose a method based on Direct Linear Transformation (DLT) and ortho-rectification method to model 3D objects combined with 3D laser scanning data and high-resolution image data.

(Uccheddu *et al.*, 2009) propose an automatic approach for mapping the texture on flat-like 3D models, where depth component is smaller compared to the object's height and width, as for bas-reliefs, coins, paintings or facades. The method relies on the evaluation of the model geometry of a depth map, used to align the texture image. In this way, the accuracy of the process depends on the registration step and not on the subjective correctness of a manual mapping.

(Gonzalez-Aguilera *et al.*, 2009) propose a co-registration approach combining high resolution images acquired with a digital camera and range images acquired by TLS. For this purpose, a feature extraction process is carried out followed by a co-registration of pair images.

The experience gained in the cave leads to similar remarks, i.e. the necessary combination of photogrammetric and laserscanning techniques. Concerning texturing, several experimentations have been performed in order to find the most appropriate one regarding the specific working conditions.

4. RECORDING METHODOLOGY

The documentation and recording processes include different steps:

- Accurate network of reference points (GPS points outside, a few marks only on paths of the cave inside), spheres and coded targets for the registration of point clouds and photogrammetric bundle adjustment;
- Overall recording by Terrestrial Laser Scanning (FARO Photon 80 and 120) at high spatial resolution;
- Overall photogrammetric recording by calibrated digital Reflex cameras (Canon EOS 5D equipped with single 28mm and 85mm lenses);
- Special surveys on some manmade depictions on walls of the cave by Imaging Total Stations (Trimble VX);
- Additional spherical panoramas capturing with Manfrotto Pan Heads.

5. ACCURATE 3D GEOMETRIC MODELS OF THE CAVE

5.1 Geodetic network

An accurate network of reference points has been setup by geodetic GPS measurements around the site. The points are marked on the areas of interest, as well as close to the cave entrance. A geodetic network links the outdoor GPS points and

a limited number of marks located on the pathway in the different galleries; these marks are used to determine accurate coordinates (about 1cm) of spheres and coded targets required for the registration of the point clouds. They are also used for the photogrammetric processing of the orientation of the images used for the texturing.

5.2 Recording of the cave by laser scanning

The FARO Photon terrestrial laser scanner has been used (Figure 2). This system is able to measure about 120000 points per second in X, Y, Z and intensity (Figure 3). One scanning session usually requires about seven minutes. The scanner is translated along the pathway in the galleries. The different point clouds are registered with at least 3 spheres displayed in the cave and visible from the scanner standpoint. The spheres are measured by the total station and therefore their coordinates are defined in the global coordinate system of the site. In a second stage, the different point clouds are registered with commercial software packages such as FARO Scene™ and Realworks™ and merged into a unique project. The overall geometric model of the cave after registration is shown in Figure 5.



Figure 2. The FARO Photon Laser Scanner in the cave

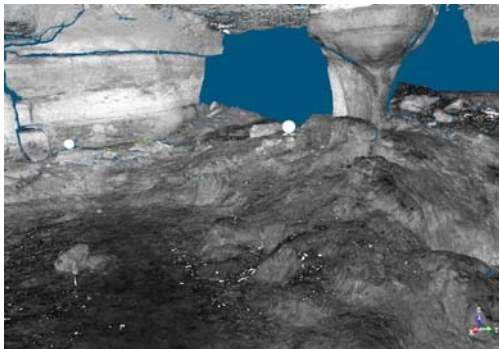


Figure 3. Intensity cloud (raw data)

5.3 Recording of the cave in 3D by laser scanning

The overall workflow showing the steps of the point clouds processing is described in Figure 4. The accurate 3D network of reference points and spheres is the mapping frame. The registration of each point cloud is achieved after the automatic measuring of the spheres in FARO Scene.

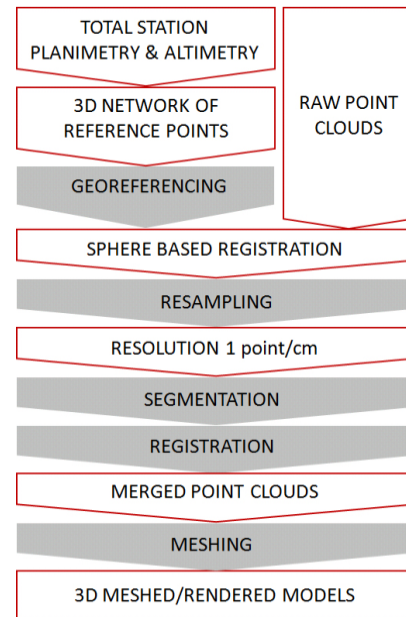


Figure 4. Workflow showing the processing steps from the raw point clouds to the geometric 3D models

5.4 Visualization of the 3D models

At this stage we consider 3D models without textures (Figures 5 and 6). As the huge amount of data is not directly usable by the archaeologists, the final models have been resampled at a spatial resolution of 1 pt/cm, and finally exported in the PDF-3D format. Thus, the user is able to handle the 3D model in the Acrobat Reader (8.0 or more) installed on his computer. This format allows as well some measuring functions and toolkits (distances, sections, etc.) and visualizations options such as wireframe, shaded, solid, vertices, etc. (meshed and rendered views are shown in Figure 6).

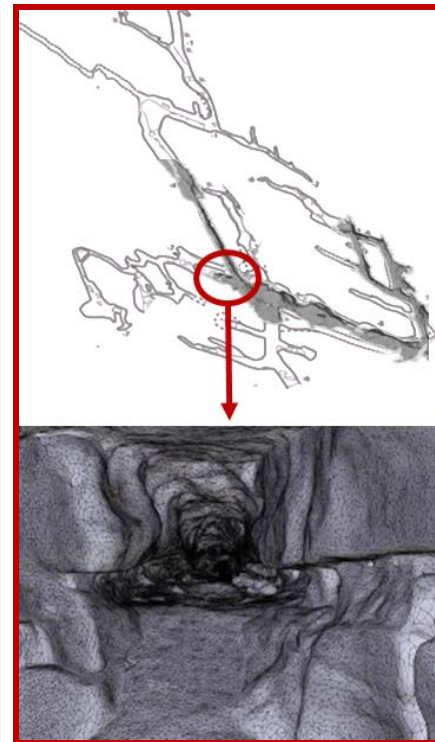


Figure 5. Overall model of the cave (status March 2010)

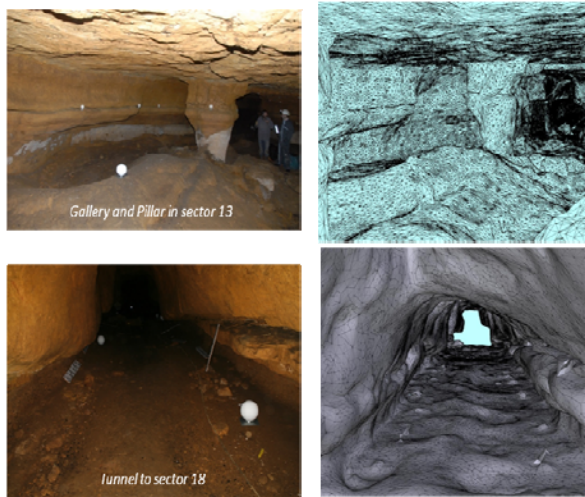


Figure 6. Examples of 3D models from the PDF-3D viewer (images on the left, corresponding models on the right)

6. TEXTURING THE 3D MODELS

For the texturing, only a few areas of interest have been processed at this stage. Different solutions for the processing of photorealistic 3D models have been tested. A summary of those solutions are presented in this section.

6.1 Texturing from Spatial Imaging Total Stations

Tachometry is traditionally used in projects needing the measurement of control networks and control points. The latest total stations include the combining of 3-D scanning, optical positioning and video technologies into a single sensor, and extend the range of applications. The Trimble VXTM spatial station (Figure 7) has been tested for this purpose.



Figure 7: The Trimble VXTM spatial station is equipped with a 3 Megapixel built-in camera (just below the telescope of the instrument)

This category of instrument is able to record a Digital Surface Model (DSM) of the object (based on a regular object grid defined by the user) and adjacent strips of images with a pre-defined overlap (Figure 8). Those images are used to colour the point clouds and to compute orthophotos or photomodels (Figure 11). However, the scanning operation with the spatial station is very low compared to the performance of a laser scanner. In Figure 12, the geometry of the model has been imported from the laser scanner raw point cloud (before its resampling to 1 pt/cm) and combined with the images shown in

Figure 8. The Trimble VXTM system delivers the position and orientation (from the total station) of each image recorded by the internal camera. The texturing of the meshed models presented in Figure 9 is therefore possible.

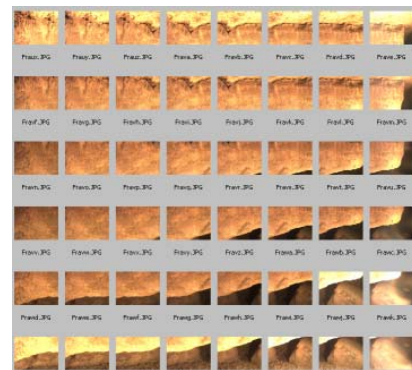


Figure 8. Set of images recorded by the Trimble VXTM spatial station available for the processing of orthophotos or textured models (Figure 11)

The performance of the internal camera of this Total Station is however limited (focal length 23mm, sensor 6.55mm x 4.92mm, 2048x1536 pixels, pixel in objet 1mm at 7m). High resolution images from reflex cameras are therefore preferred for the visualization of parietal art details (Figure 16).

6.2 Texturing from high resolution images

In this project, beside the medium resolution images from the Trimble VXTM spatial station, two other types of high resolution digital images are available for texturing. An important set of images from a Nikon D200 camera was available, also dedicated to the overall documentation of the cave. Another set of images from a calibrated Canon EOS 5D SLR camera equipped with a 28mm objective and flash ring has been recorded. The exterior orientation (position and direction) of these images is required for the texturing. Such a process is possible by identifying a set of corresponding points in the image and the point cloud. At this stage of the project, research is currently made in order to automate the process, since the identification of corresponding points is endless. Up to now, texturing has been performed manually.

6.3 Summary of the workflow

The main steps of the workflow to get textured models from the previous results are given in Figure 9.

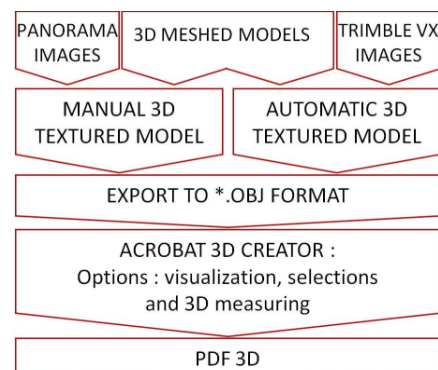


Figure 9. Texturing workflow from SLR cameras or Trimble VX images

6.4 Examples of textured models

The following models are based on triangulated DSM from the Trimble VX total station (Figure 11) or from the laser scanning survey (Figure 12). The point clouds used for visualization purposes in the Figures 5 and 6 have been resampled to 1pt/cm while the textured model of Figure 12 has been resampled to 1pt/mm in order to get a better rendering and to avoid any loss of geometry.



Figure 10. Recording of a clay panel with the Trimble VX™

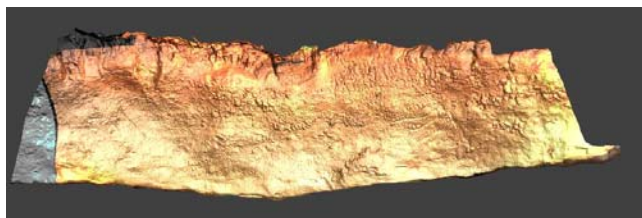


Figure 11. Textured 3D model of a clay panel recorded with the Trimble VX™ (images and simplified point cloud)

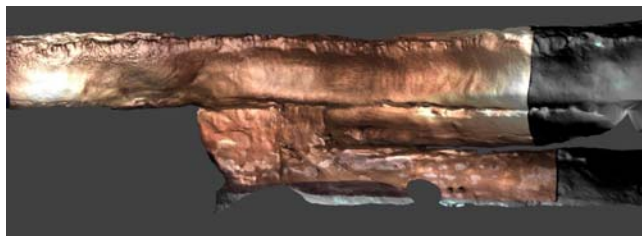


Figure 12. Texturing of the 3D model obtained by projection onto a high resolution DSM of 1 point/mm from the FARO scanner and the Trimble VX™ images

6.5 Exterior image orientation processing

For the Trimble VX images, the exterior orientation parameters of the images are given by the total station. It is therefore easy to process the images and the point clouds together. For the processing of the parameters of the SLR camera images (Canon EOS 5D), the function of identification of the coded targets in the PhotoModeler software helped to automate the process of orientation (Figure 13).

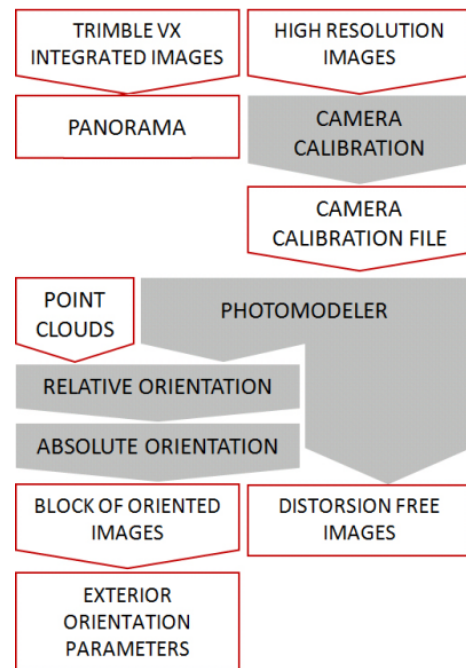


Figure 13. Workflow showing the processing of the exterior image orientation

6.6 Point cloud colouring

Considering the exterior orientation of the images from the previous processing, and the different point clouds after the registration stage, a process based on the collinearity relations has been applied for the colouring of the different point clouds (Figure 14). The display of the coloured point clouds is a simple way to visualize the data without considering the time-consuming processing of meshing.

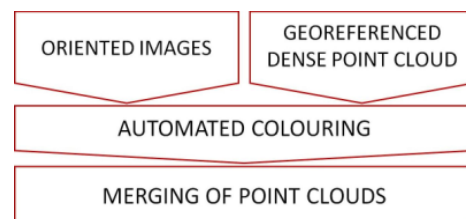


Figure 14. Processing of coloured point cloud

6.7 High resolution panoramas

Contrary to basic solutions of panoramic photography where super wide-angle optics or a fish-eye lens are used, we show in Figures 15 and 16 the result of a panorama computed with a 85mm lens mounted on the Canon EOS 5D camera. This lens used at a distance of 5m from a clay panel with original finger marks delivers a pixel size of 0.5mm in the object (Figure 16). The camera has been calibrated and distortions free images have been processed prior to the stitching of this large panorama image with the PTGUI Pro software.



Figure 15. Panoramic photography head

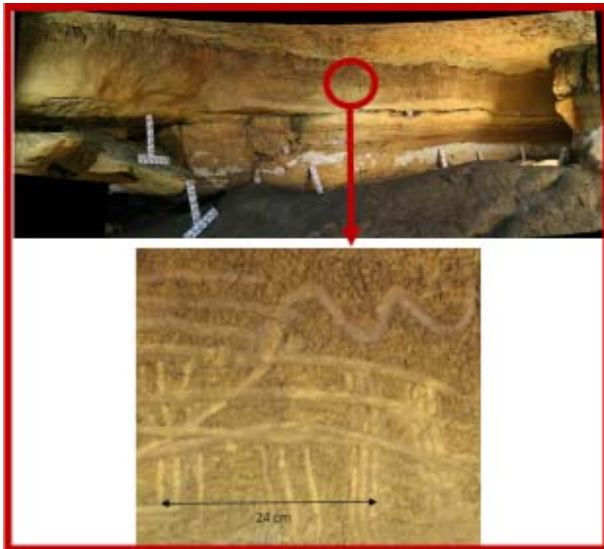


Figure 16. Panoramas and zoom on details for very accurate parietal art feature visualization at 0.5mm resolution (pixel size in the resulting panorama)

7. CONCLUSION

The aim of this documentation work has been to generate geometric and photorealistic georeferenced 3D models from the combination of laser scanner point clouds and photogrammetric images, for both resolution recording and visualization purposes. The project is challenging because of the complexity of the shapes of the cave which differ from regular outlines and surfaces of built structures usually processed in archaeology or architecture. Although laser scanning and photogrammetry can be considered as mature techniques, this project shows that developments of specific solutions are required in order to meet the need of the users in such a multidisciplinary project. For the archaeologists, the documentation and recording works are important contributions. Georeferenced surveys and images of the remains as well as the structural elements and sculptures have been acquired in different parts of the cave. Furthermore, another purpose of the recording is to deliver data and models in formats that can be handled by most of the partners involved. The 3D models recorded as 3D-PDF format files presented as examples in this paper are therefore the support for new methods of investigation for the users.

References from Journals:

Gonzales-Aguilera, D., Munoz-Nieto, A., Gomez-Lahoz, J., Herrero-Pascual, J., Guitierrez-Alonso, G., 2009. 3D Digital surveying and modelling of cave geometry: Application to Paleolithic Rock art. *Sensors* 2009, 9, 1108-1127.

Lerma, J., Navarro, S., Cabrelles, M., Villaverde, V., 2009. Terrestrial laser scanning and close range photogrammetry for 3D archaeological documentation: the Upper Palaeolithic Cave of Parpalló as a case study, *Journal of Archaeological Science*, Volume 37, Issue 3, Pages 499-507.

Remondino, F., El-Hakim, S., 2006. Image-based 3D modelling: a review, *The Photogrammetric Record* 21 (115) (2006), pp. 269-291.

References from Books:

Schaich, M., 2007. From 3D Scanning to Analytical Heritage Documentation. Chapter in Book Series Springer Proceedings in Physics, Springer Berlin Heidelberg (Eds), *Lasers in the Conservation of Artworks*, ISBN: 978-3-540-72129-1. Volume 116, pp. 463-471.

Grussenmeyer, P. & Hanke, K., 2009. Cultural Heritage Applications. Chapter in Vosselman, G. & Maas, H.G. (Eds). *Airborne and Terrestrial Laser Scanning*. Whittles Publishing, ISBN-10: 190444587X, ISBN-13: 978-1904445876, pp.271-290.

Patias, P., Grussenmeyer, P. & Hanke, K., 2008. Applications in Cultural Heritage Documentation. In: Li, Z., Chen, J., & Baltsavias, E., (eds.): *Advances in Photogrammetry, Remote Sensing and Spatial Information Sciences*: 2008. ISPRS Congress Book, ISPRS Book Series, Volume 7 (527p.), © 2008 Taylor & Francis Group, London, ISBN 978-0-415-47805-2, pp. 363-383.

References from Other Literature:

El-Hakim, S. F., Fryer, J. G. and Picard, M., 2004. Modelling and visualization of aboriginal rock art in the Baiame cave. *ISPRS International Archives of Photogrammetry and Remote Sensing*, 35(5): 990-995.

Fryer, J.G., Chandler, J.H., El-Hakim, S.F., 2005. Recording and modelling an aboriginal cave painting: with or without laser scanning. In: 1st 3D-ARCH International Symposium, Mestre-Venice, Italy. *Int. Archives of Photogrammetry, Remote Sensing and Spatial Information Systems* Vol. XXXVI-5/W17 ISSN 1682-1777, 8 p.

Grussenmeyer, P., Cazalet, B., Burens, A., Carozza, L., 2010. Close range terrestrial laser scanning and photogrammetry for the 3D-documentation of the Bronze Age cave "Les Fraux" in Perigord (France). *Proceedings of the Mining in European History Conference*, Innsbruck (Austria), Nov. 12-15, 2009, in print.

Uccheddu, F., Del Mastio, A., Remondino, F., Pelagotti, A., Cappellini, V., 2009. Texture mapping of flat-like 3D models. 16th Int. Conference on Digital Signal Processing, 5-7 July, Santorini-Hellas, ISBN: 978-1-4244-3297-4, pp.1-6,

Zhang, Y., Yan, L., Lu, X., 2006. Precise texture modeling with 3D laser scanning. *Proceedings of SPIE*, Geoinformatics 2006 (Remotely sensed data and information : 28-29 October, Wuhan, China), vol. 6419, ISSN 0277-786X, 9p.

Reference from website:

Blog of the project: <http://champslibres.hypotheses.org/>