3D modeling and mud brick conservation at Tell Timai, Egypt

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Abstract: In 2013, a new conservation effort and research was implemented at the Tell Timai excavation in Egypt. Archaeological conservation has been considered more and more as an indispensable tool of archaeological fieldwork. In order to optimize the conservation and documentation process the new strategy employed combines 3D modeling with preservation of the archaeological data.
The project served to create a photometric documentation for some of the most at-risk structures, to start an image database set for future erosion monitoring within the site and to research the benefits of using 3D modeling technologies in conservation projects to improve the preservation of earthen architecture.

Keywords: earthen conservation, digital preservation, three-dimensional registration, agisoft, photogrammetric modeling

Introduction

Archaeological conservation has been considered more and more as an indispensable tool of archaeological fieldwork. This paper offers a preliminary result of new conservation strategy, which combines 3D modeling and mudbrick preservation, implemented in Tell Timai during the June-July 2013 season. Tell Timai is a unique and outstanding example of Graeco-Roman mud brick architecture and it represents one of the best-preserved sites in the Egyptian Delta. Tell Timai, ruins of the Greco-Roman Egyptian city of Thmuis, is located in the Delta region of Egypt near the modern city of El-Mansoura. Thmuis is about a half kilometer south of Tell el Rub'a, the site of the ancient city of Mendes

In the last years, investigations using 3D applications in archaeological studies have mainly focused on the registration and preservation of heritage (CHANDLER ET AL., 2007; SIMPSON ET AL., 2004; ORENGO 2013; DE REU ET AL 2013; RUA AND ALVITO, 2011; PLETS ET AL., 2012; KOUTSOUDIS ET AL. 2014). However, the application of 3D technology in archaeological conservation of architecture remains limited and mostly used as a documentation tool. It is only infrequently employed as an instrument to improve architectural conservation in archaeological sites (DE REU ET AL 2013; KOUTSOUDIS ET AL. 2014; BARTON 2009).

Barton's research (2009) shows the potential for 3D registration in archaeological and cultural heritage studies of earthen architecture. Several other researchers have combined 3D laser scanning with GPS recording and 3D GIS to obtain full 3D geo-referenced models (APOLLONIO ET AL. 2013; MCPHERRON ET AL., 2009; PAVLIDIS ET AL., 2007 ; KOUTSOUDIS ET AL., 2014; ORENGO 2013; YASTIKLI, 2007). Most of those studies are divided into image-based model and range-based model or a combination of both (REMONDINO ET AL. 2006; VERHOEVEN 2011). This latter approach is what we have deemed to be more appropriate for our case study in Tell Timai. The model should fit multiple purposes:

1. To create a photometric documentation for the most at-risk structures.
2. To start an image database for future erosion monitoring.
3. To research the benefits of using 3D modeling technologies in conservation of earthen architecture.

During the 2013 summer field season at Tell Timai mudbrick structures from two different areas on site (L14 and Q13) were 3D modeled by means of photogrammetry, where both aerial and ground-based 3D models were created. The two areas that are the focus of this work are designated grid Q13 and grid L14. Grid Q13 contained a series of structures on either side of a street. These are likely to be residential Grids, whose last phase dates to the Late Roman Period. Grid L14 contained a large public building that is also dated to the Late Roman Period.

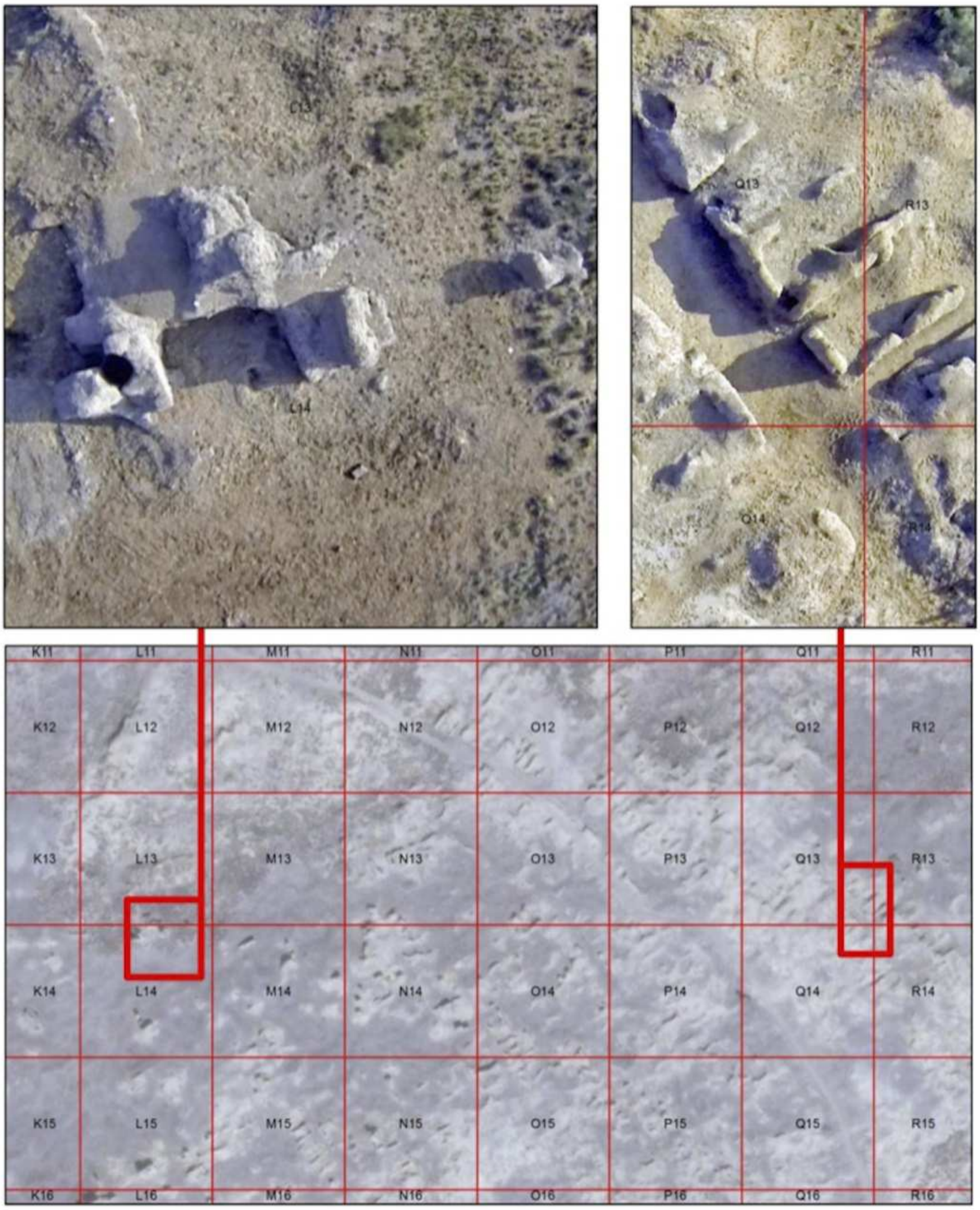

Fig. 1 – Maps of areas where conservation was completed (Copyright: Tell Timai Excavation)

These 3D models were created in order to conduct a general assessment and condition report of the structures. They were used in preparation for conservation to target areas in need of intervention, as well as in determining the best method of intervention in each case. They can also be used for long-term monitoring of the structures condition.

Methodology

In order to capture the images for the 3D models two distinct methods were employed. The first method was a ground-based method of capture using a Canon 5D Mark II camera with a 50mm lens. Since it is necessary to have plenty of overlap between photos in a series for 3D modeling (Agisoft LLC 2012: 4), all photos were taken with a minimum of 60% overlap sequentially in each series. For the closest details of the mudbrick walls the camera was held on a monopod and a remote shutter released was used. For the mid-range photos the camera was handheld. For the mid-range photos, the rugged terrain of Tell Timai was exploited, where photos were taken standing on areas of higher elevation that surrounded the subject. In each area (Grid L14 and Grid Q13) a series of photos were taken using a specially made steel pole approximately 5 meters in length and a remote camera control system (Polaroid Wireless Viewfinder and Trigger System).

Fig. 2 – Overlapping photos of mud brick walls in Street #1 (Copyright: Tell Timai Excavation)

For grid Q13 the aim was to create an individual 3D model for the face of each of the standing walls on the northeastern side of Street #1 and one 3D model of grid Q13 overall including Street #1 and surrounding structures. A series of close-range photos were taken at approximately 1 meter intervals for modeling the individual walls. Each series included 20 photos that were used to process a final model. A series of mid-range photos taken at approximately 1 meter intervals along with a separate series of photos using the steel photo pole were taken for modeling grid Q13. Grid Q13 consisted of a street and ruined mudbrick structures covered in a fine layer of light brown silty soil. The scene was fairly monochromatic and features were difficult to distinguish in ground-based photos, therefore ground control points were employed in order to help the software locate matching points and insure proper alignment. Two types of ground control points were used: small points (caps of a standard 1.5 liter plastic water bottle) and larger points consisting of cloth bags with dimensions of about 30 cm by 50 cm. The series included 48 photos that were used to process the final model.

For grid L14 the aim was to create two 3D models: one of the best preserved portion of Building #1 (which would receive intervention) and one 3D model of grid L14 overall, showing the full visible extent of Building #1 and its immediate surrounding area. For the model of Building #1 series of close-range detail photos were taken of Building #1 along with a series of mid-range photos taken at approximately 2 meter intervals. A total of 136 photos were used to process the final model. For the model of grid L14 a series of mid-range photos taken at approximately 2 meter intervals along with a series of photos using the steel photo pole, creating a total of 148 photos that were used to process the final model.

A second, aerial capture method was also used in order to create two additional 3D models: one of the overall area of grid Q13 and one of the overall area of grid L14. This system included a DJI phantom quadcopter equipped with a GoPro camera. The quadcopter (operated by Israel Hinojosa) made flights of approximately five minutes in length during which the GoPro camera captured approximately 500 photos. Due to the level of distortion in photos taken by the GoPro a certain amount of processing was required before they could be used to create 3D models. All photos captured by the GoPro camera were batch processed in Adobe Photoshop CS3 using an algorithm built by Israel Hinojosa that produced undistorted photos. A total of 49 photos were selected to create the 3D model of grid Q13 and a total of 155 photos were selected in order to create the aerial 3D model of grid L14.

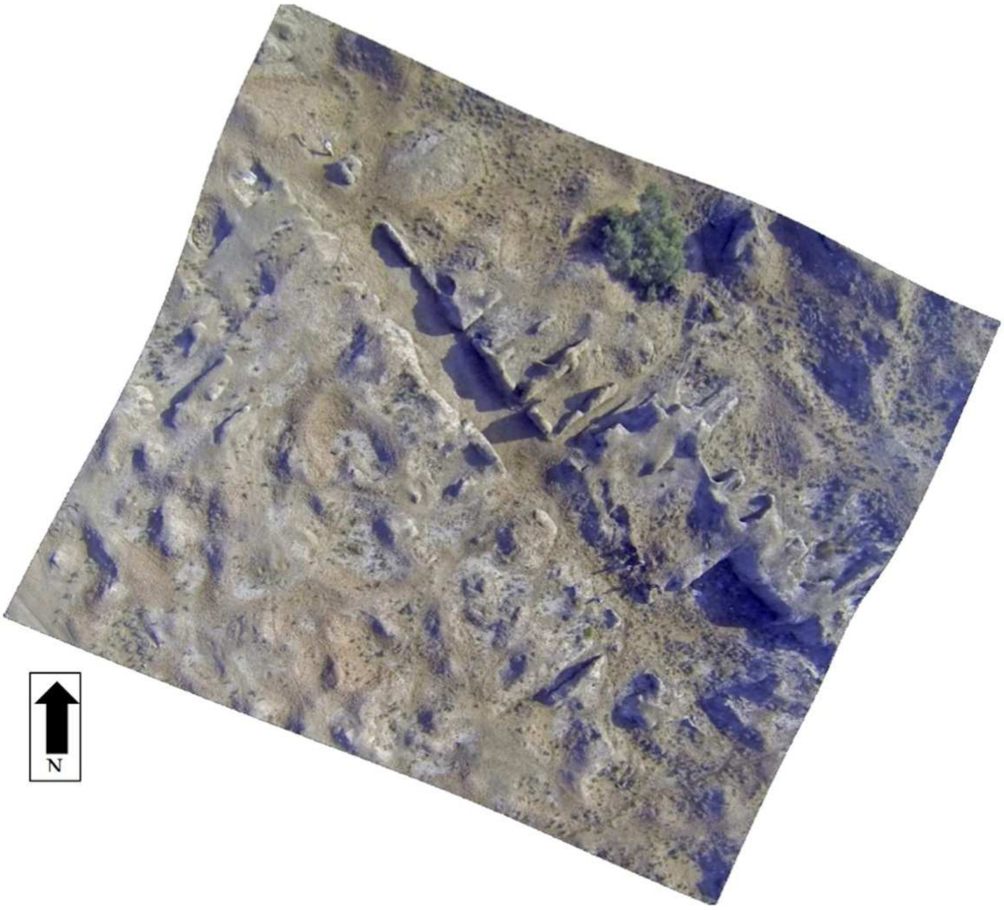

Fig. 3– Aerial View of Street #1 (Copyright: Tell Timai Excavation)

The 3D models were rendered using Agisoft Photoscan. In processing the ground-based 3D models the photo alignment was set to a medium accuracy and geometry building was set to arbitrary object type and sharp geometry. The texture was generated for the ground-based 3D models with the blend-mode set to generic. In processing the aerial 3D models the photo alignment was set to a medium accuracy and geometry building was set to height field object type and smooth geometry. The texture was generated for the aerial 3D models with the blend-mode set to Adaptive orthophoto. The steps within the workflow were set to the parameters recommended by Agisoft in the Photoscan User Manual (AGISOFT LLC 2012: 8-10).

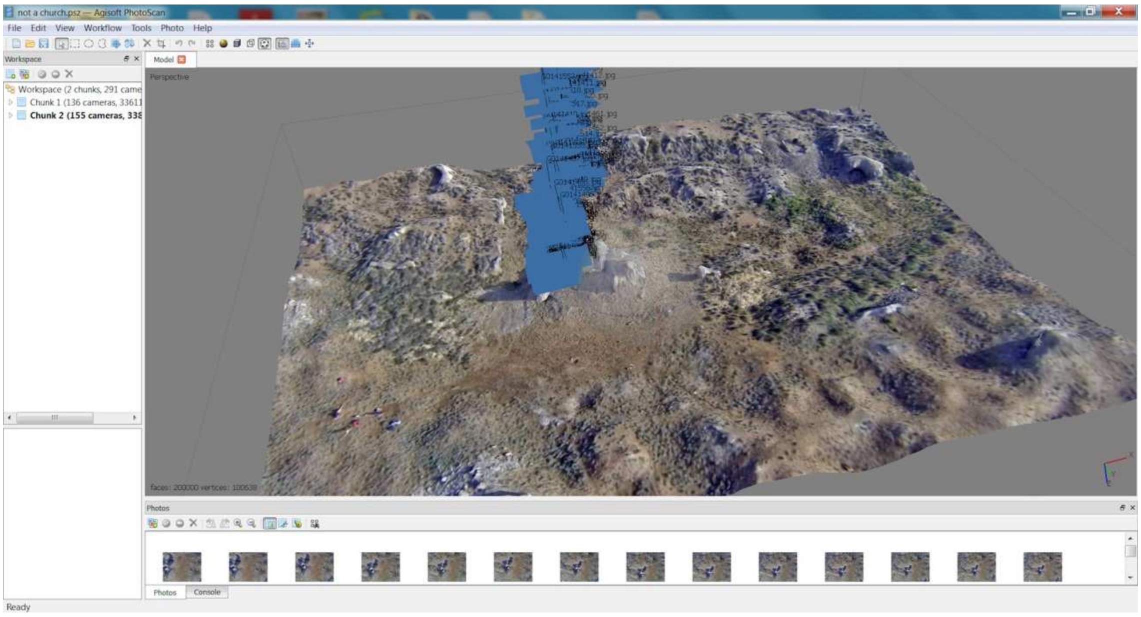

Fig. 4 – 3D modeling using Agisoft PhotoScan (Copyright: Tell Timai Excavation)

Results

The two 3D models of grid Q13 and grid L14 created using the aerial photos were satisfactory in both resolution and accuracy. It was possible to highlight the main conservation issues and the fissures up to a detail of 2 cm. 3D models created using photos captured using the ground-based method were only successful for the individual walls of grid Q13 and the best preserved portion of Building #1 in grid L14. The ground-based 3D models of the overall areas of both grid Q13 and grid L14 were not able to be rendered successfully. Due to the inconsistencies in the two capture systems, the ground-based and aerial photos could not be merged to create 3D models of grid Q13 or grid L14 using both photo sets.

After an initial attempt to create a 3D model of grid Q13 using a ground-based photo set, it became clear that the preserved height of the mudbrick walls was not sufficient for successful 3D modelling using Agisoft Photoscan. An attempt was also made to create a 3D model of grid L14, however only Building #1 was preserved sufficiently for a 3D model to be successfully created with the ground-based photos. In this respect, the 3D models created with the aerial photos gave the desired perspective while the 3D models created using the ground-based photos provided a more detailed view of the architectural remains. The changes made to the GoPro photos caused an inconsistency in the color data with the ground-based photos that prevented the two-photo set from being merged into a 3D model through Agisoft PhotoScan.

Given the results of 3D modeling grid Q13 and grid L14 during the 2013 field season, it is clear that both the aerial and ground-based methods of image capture are necessary for creating 3D models of the mudbrick architecture at Tell Timai. Both methods will continue to be employed in future work at the site. It would be highly desirable to be able to merge both ground-based and aerial photo sets, however doing so would likely mean amending the aerial system so that it employs a more compatible DSLR camera with that of the ground-based system and a sufficiently sized UAV to support it.

3D and Conservation

The compilation of a detailed 3D representation of archaeological data is of great importance for documentation and highly desirable and for restoration purposes. Although two-dimensional (2D) images could work well for a condition assessment, a photograph alone is inadequate to convey the complexity and the variation of three-dimensional architectural structure. For instance, the way in which two walls are interconnected and how the structural forces work on a building is better conveyed by a 3D model.
The ongoing development of such techniques allows a broader use of them in activities related to any branch of archaeological fieldwork, and consequent archival documentation.
In conservation a 3D model of the entire building is really important in order to understand and analyze:

- Function and Space;
- Deterioration processes;
- Possible conservation options

Fig. 5 – 3D model of Building #1 (Copyright: Tell Timai Excavation)

This later point is particularly relevant as the creation of shelters and reburials - usually the most desirable conservation practices - are not always possible, as is the case of the structures at Tell Timai.
Archaeology must focus more on conservation, and the use of 3D modeling allows a better understanding of earthen architecture regarding structural problems, space patterns, preservation issues and possible conservation interventions.

Mudbrick Conservation in Tell Timai

In this case study the 3D model was used as a reference for the condition assessment conducted during the season (June-July 2013) to analyze and record the physical condition of the at-risk earthen structures. Thanks to the model it was easy to investigate the conditions of the standing architecture, including the structural system, building materials, finishes, environmental conditions, spatial relations of architecture, and decay processes. Consequently a conservation plan was developed to preserve the standing architecture at risk. The areas analyzed and conserved during the 2013 season included: an outstanding mudbrick building - Building #1 in the L14 area- and an open area - officially known as Street #1 in Q13.

The structures have been compromised by natural elements, human traffic and the presence of feral dogs. The buildings showed a series of deterioration from spalling, material loss, mud-brick crumbling and fissuring leading to a more extensive failure of parts of the structures.

The 3D model highlights how the building condition varies depending on the orientation of individual walls. The models also helped to reconstruct the buildings size and showed the structures' complex plan. A 3D reconstruction clearly shows that interior and exterior walls, which face the same direction, received similar exposure from deterioration agents, presenting similar erosion patterns.

The methodology employed to preserve the archaeological remains is based on the use of traditional materials, which proved effective in the past in preserving mudbrick architecture. During the 2013 season we stabilized the situation by reconstructing damaged parts of original mud-brick walls, stopped the spalling and counteracted the soil pressures by mortar injection and plastering with traditional mud-plaster.

To improve the critical structural points showed in the reconstruction we decided to support the spalling walls with new mud bricks. One of the main highlights of the conservation project was the creation of our own mudbricks to support the old wall. In doing so we used the same chain of production employed in the last four millennia in Egypt. We tested the difficulties in creating the right sediment composition and then we researched the best construction techniques.

The ability to preserve the standing mudbrick architecture is essential for the scientific data and also for tourism and educational purposes. Additionally, the preservation through new mud bricks gave us the opportunity to create new 3D models in order to monitor the conservation performance and the building condition. All the interventions carried out were reversible and preserve the integrity and the authenticity of the walls.

Fig. 6 – Mud brick Manifacturing (Copyright: Tell Timai Excavation)

Fig. 7 – Reinforcing of a wall in Street #1 (Copyright: Tell Timai Excavation)

Conclusions

The compilation of a detailed 3D representation of archaeological remains is of great importance, either for documentation needs or for restoration purposes.

This paper aimed at offering a preliminary result of a project that combines 3D modeling with conservation of the archaeological data.

As presented, the 3D model of the entire building was critical to our understanding of building size, to complete the condition assessment, and to assess possible conservation options. The models also fulfill additional purposes: to create a photometric documentation for the most at-risk structures, to start an imaging database for erosion monitoring and finally to illustrate the benefits of using 3D modeling technologies in conservation of earthen architecture with the creation and comparisons of pre/ post conservation models.

The necessary 3D data was derived from photogrammetric techniques using the software package Agisoft Photoscan Standard. Our methods for creating 3D models include the use of undistorted aerial photos taken by remote control quadcopter and terrestrial photos taken using a full frame DSLR. The software is cost effective and our hardware requirements were minimal including the use of digital cameras, making it easily and extremely efficient in the field.

Finally the development of the most common 3D modeling techniques has made it possible to employ the model as a tool for condition assessment and imaging database, which can be exported in a variety of forms including Adobe PDF. It has been shown to be preferable to disseminate this data in the form of a PDF, which is a published and nearly universally accessible format.

Reference

AgiSoft LLC, 2012. AgiSoft PhotoScan User Manual: Standard Edition, Version 0.9.0.

AgiSoft LLC. AgiSoft LLC, 2012. Agisoft PhotoScan. Professional Edition, Version 0.9.0. http:// www.agisoft.ru/products/photoscan/.

APOLLONIO, F. I., GAIANI, M.,BENEDETTI,B., 2012. 3D reality-based artefact models for the management of archaeological sites using 3D GIS: a framework starting from the case study of the Pompeii Archaeological area, Journal of Archaeological Science, Volume 39, Issue 5, May 2012, 1271-1287

BARTON J., 2009. 3D laser scanning and the conservation of earthen architecture: a case study at the UNESCO World Heritage Site Merv, Turkmenistan, World Archaeology,Vol. 41, Iss. 3, 2009

CHANDLER, J.H., BRYAN, P., FRYER, J.G., 2007. The development and application of a simple methodology for recording rock art using consumer-grade digital cameras. The Photogrammetric Record 22 (117), 10-21.

DE REU, J., PLETS, G., VERHOEVER, G., DE SMEDT, P., BATS., M., CHERRETTÉ B., DE MAEYER W., DECONYNCK J., HERREMANS, D., LALOO, P., VAN MEIRVENNE M., DE CLERCQ, W., 2013 Towards a three-dimentsional cost-effective registration of the archaeological heritage. Journal of Archaeological Science 40(2013) 1108-1121

KOUTSOUDIS, A., PAVLIDIS, G., ARNAOUTOGLOU, F., VIDMAR ,B., IOANNAKIS, G.,.CHAMAZ, C,., 2014. Multi-image 3D reconstruction data evaluation. Journal of Cultural Heritage 15 (1), 73-79.

MCPHERRON, S.P., GERNAT, T., HUBLIN, J.-J., 2009. Structured light scanning for high- resolution documentation of in situ archaeological finds. Journal of Archaeological Science 36 (1), 19-24.

ORENGO, H.A., 2013 Combining terrestrial stereophotogrammetry, DGPS and GIS-based 3D voxel modelling in the volumetric recording of archaeological features, ISPRS Journal of Photogrammetry and Remote Sensing, Vol. 76, February 2013, 49-55

PAVLIDIS, G., KOUTSOUDIS, A., ARNAOUTOGLOU, F., TSIOUKAS, V., CHAMZAS, C., 2007.Methods for 3D digitization of cultural heritage. Journal of Cultural Heritage 8 (1), 93-98.

PLETS, G., VERHOEVEN, G., CHEREMISIN, D., PLETS, R., BOURGEOIS, J., STICHELBAUT, B., GHEYLE, W., DE REU, J., 2012 The deteriorating preservation of the Altaian rock art – Assessing three-dimensional image-based modelling in rock art research and management. Rock Art Research 29 (2), 139-156.

REMONDINO, F., EL-HAKIM, S., 2006. Image-based 3D modelling: a review. The Photogrammetric Record 21 (115), 269-291.

RUA, H., ALVITO, P., 2011. Living the past: 3D models, virtual reality and game engines as tools for supporting archaeology and the reconstruction of cultural heritage e the case-study of the Roman villa of Casal de Freiria. Journal of Archaeological Science 38 (12), 3296-3308.

SIMPSON, A., CLOGG, P., DÍAZ-ANDREU, M., LARKMAN, B., 2004. Towards three- dimensional non-invasive recording of incised rock art. Antiquity 78 (301), 692-698.

VERHOEVEN, G., 2011. Taking computer vision aloft e archaeological three-dimensional reconstructions from aerial photographs with photoscan.Archaeological Prospection 18 (1), 67-73.

YASTIKLI, N., 2007. Documentation of cultural heritage using digital photogrammetry and laser scanning. Journal of Cultural Heritage 8 (4), 423-427

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