Преглед НЦД 28 (2016), 55–63

Jugoslav Pendić
Center for Digital Archaeology, Faculty of Philosophy
Branislava Lazarević Tošović, Marko Aleksić
Central Institute for Conservation in Belgrade
Andrej Žitňan, Zuzana Rejdovianová
VIA MAGNA, Martin, Slovakia
Jiří Hrubý, Daniel Hlásek
TerraVerita, Prague, Czech Republic

3D TECHNOLOGIES IN CONSERVATION OF CULTURAL HERITAGE: MONITORING OF THE NEOLITHIC STRUCTURES FROM ARCHAEOLOGICAL SITE BELO BRDO IN VINČA

Abstract. Documenting cultural heritage in interactive 3D format is becoming more and more affordable, easy-to-obtain and implement procedure. Not so long ago, there could be heard voices complaining the lack of full accuracy tests of the automated procedures for extracting 3D data from imagery (1) - and presently we are seeing numerous, tested and actively used solutions, that can even be overly simple for use, although the latter is depending on the eye of the observer and specific needs and portfolio of an individual/project. Furthermore, as the methods have become widely available, an important question is presented: how justified it is to invest effort and funds into the creation and storage of 3D models and collection of datasets, if a limited area of use is intended. Or to ask it more directly, is it really necessary, and what else can be made out of these collections, besides presentation material and snapshots-in-time of a given feature.

The paper will present an effort to offer additional meaning to photogrammetric data acquisition in archaeology, apart from it being an advanced documentation system. We tested different approaches in monitoring the state of preservation of an important Neolithic household structure, using SFM workflow combined with an active 3D scanner to evaluate conservation procedures performed on it. The structure is located in a dynamic background of multilayered archaeological site Belo Brdo in Vinča, which is undergoing its latest phase of field research, spanning from 1998 up to present.

Keywords. archaeology, Neolithic, conservation, 3D documentation, photogrammetry, 3D scanning

Introduction

Prehistoric settlement at Belo Brdo in Vinča is one of the most significant monuments of cultural heritage situated on the territory of Belgrade and Serbia. Seven millennia ago, a large center of late Neolithic culture was founded there, booming with life and activity. Impressive archaeological finds originating from Belo Brdo, alongside remains of up to 10 meters high cultural layers, have put this site to the cultural map of Europe. On the site, area marked as Sector II in official documentation was recognized as being of special importance, and has been excavated ever since 1978 (Figure 1b).

During the late Neolithic period, in the 800 years between 5300 and 4500 BC, on a mildly elevated river terrace, settlements followed one after another in succession, the new ones resting on the remains of the old, eventually resulting in a creation of the artificial hill of Belo Brdo, with its powerful profile section showing the whole span of time, as consequence of human agency (Figure 1c).

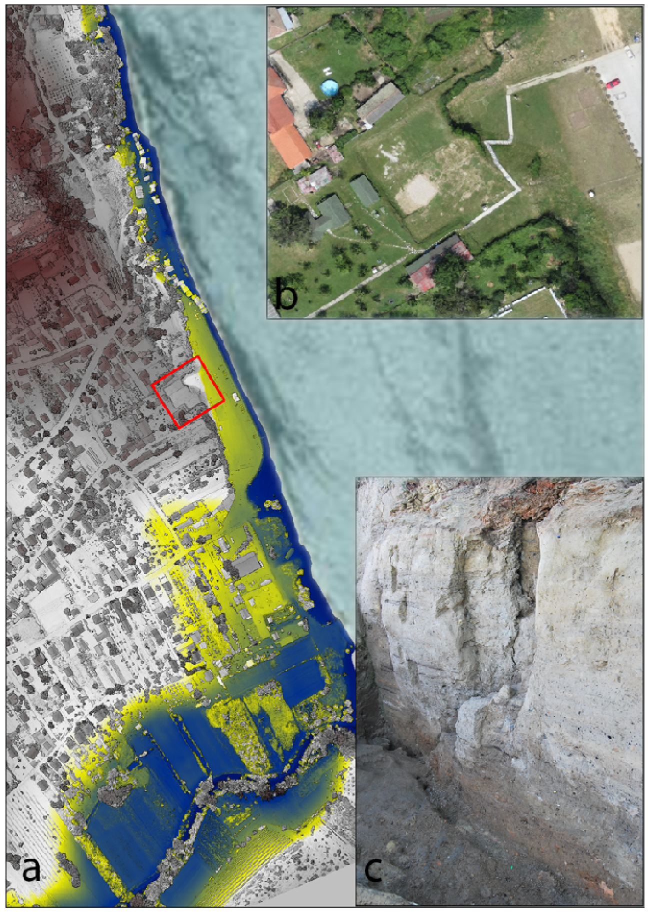

Figure 1: a) view of DSM of Vinča - modern settlement b) Sector II on aerial imagery c) segment of site's profile

In the process of archaeological research of the site, during campaigns running between 1998 and 2009, a team of conservators was involved, tasked purely with the on-site conservation issues. Their participation in planning of fieldwork activities and operational workflow was, in more than one case, crucial for the fate of discovered artifacts and unmovable features made of **earthen materials**, which present a very special issue. Earthen materials, largely represented in prehistoric archaeological sites have been somewhat neglected in relation to the others in the field of conservation, although their specificity raises a number of different problems. Earthen archaeological remains, besides organic, are among the most delicate to deal with due to their properties. Extremely sensitive to weathering and highly hygroscopic, they are susceptible to variety of deterioration processes. On multilayered archaeological sites, like Belo Brdo, parts of structures, constructive materials, and the interior plan have suffered greatly due to various anthropogenic and natural post depositional activities, and were mostly found in very bad state of preservation. The protection of the Belo Brdo site is certainly not a simple matter, and with the deterioration of even the smallest parts of it, a stage in continuity is lost, and a real danger of being unable to analyze material traces of past societies is introduced.

After a massive collapse of the site profile in May 2010, archaeological excavations of Sector II was put on hold, and layers that were excavated in previous years were conserved at the level of burnt remains of late Vinča period (Vinča D) dated between 4800 and 4500 years BC. In the spring of 2011, using a complex protective covering system consisting of geo-textile, sand, geo-mesh and gravel, features labelled as structure 03/03 and 01/06 were reburied and protected from harmful impacts and gradual decomposition, and their state of preservation was controlled on regular basis.

Using archive imagery of these features, recorded at the stage before initial conservation took place, and imagery and active sensor data collected during the period of control, undertaken in 2015, an attempt to estimate the percentage of trauma affecting protected surfaces, and the degree of geometric change of archaeological remains was undertaken. Having in mind that there are no means to halt the passage of time, our goal was to establish the success rate of methods and approaches used for conservation in 2011, and also, to use some of the newest technical solutions in digital documentation for cultural heritage purposes. Using a lightweight and transportable FARO 3D scanner, DSLR camera configuration and specialized, freely available and commercial photogrammetry software, we use the example of Neolithic structure 01/06 to assess the effectiveness of the conservation process, and in the same time, the effectiveness and application of advanced 3D documentation for archaeological purposes.

Applied photogrammetry in Archaeological Context

Methods and detailed studies of SFM workflow have been documented on more than one occasion (2)(3)(4), so they will not be dealt with in detail here. Structure-from-motion reconstruction, now being a practice done by amateur and professionals alike, has proven to be an invaluable tool in situations where speedy and cost effective approach is advised. Tools are easy to obtain, easy to configure to a specific need, and the authors of this paper have, in course of their engagement with the methodology, found more than one way to make data of this type meaningful. This brings the discussion to the question and importance of "why",more than "how". One of the principal characteristics of the SFM is that only minute knowledge is enough to get one started - to achieve better quality products from effort invested, careful study, good preparation and more advanced equipment are needed however, and one needs to be certain that this will bring forth results relevant to the needs and comparative to the cost of the works. As one of the authors have had the chance to hear in a personal communication when discussing the precision of SFM reconstruction: "Whomever opts to use it, knows already that it is precise enough". This explanation, coming from a professional fieldworker engaged on a daily basis with high-precision recording of whole landscapes from aerial imagery, although bit crude in nature, in reality explains it well: intended use, defines and justifies the procedure. We based our study on the fact that SFM is well-established and reliable manners of documentation (5).

When documenting structure 01/06, effort was made to use all means that were easily obtainable and already on hand(Fig 2), and no expense was saved on iterations of approach. Since the structure was revealed for a limited time (few days only) we used this window of opportunity to take the necessary number of photos under different lightning conditions (overcast vs. intense sun), different camera networks (with different camera configurations) and using more than just one known way of 3D documentation. At the moment in Serbia the most widespread tool is Agisoft Photoscan(6) which is an excellent solution for all enterprises, but is a commercial product - any researcher wishing to avoid investing into it, has a number of other solutions available. It is important to stress that the software needed for the post-acquisition processing exists also under non - commercial licensing, i.e. open software solution are also available.

Figure 2: left - active sensor acquisition, right - SfM imagery acquisition

The workflow for SFM has been designed to incorporate freely available solution for camera network reconstruction, VSFM (http://ccwu.me/vsfm/) while dense point cloud generation was carried out by SURE (http://nframes.com/) - surface reconstruction from imagery software, made available to our use for a period of time by the manufacturer. This solution has proved to give very detailed and noise free point clouds, providing high level of control over parameters involved, and more important - very speedy and accurate reconstruction (8).

Photos have been taken using highest quality mode compressed jpg format - **for this use** we estimated that gain from raw format photos would not account for high storage consumption, and that benefit would not be of note. Photos were taken in nadir and oblique (convergent) manner, to provide total coverage of the feature, and all surfaces, planar and otherwise, a good practice because final results can branch out in several directions and the high completeness of point cloud model is desired (meaning high degree of overlap & short baseline imagery) alongside with accurate reconstructions (introducing wide baseline& convergent images) and also good choice of textures for final (ortho) plan (nadir images) (7). In the end, 3 sets of several hundred photos each were created, covering the whole extent of F01/06 plan, with special attention given to the oven found inside one of the rooms. This oven was found in a remarkably well state, having suffered very little damage thorough post deposition and excavation processes (Figure 3).

The final goal was to get noise free, high precision, detailed measurement of the whole area, with the highest possible completeness of the data (as few gaps as possible, in accordance with the flaws of the methodology). These would be used in comparison with imagery acquired in 2006, in quite similar manner (with the lack of oblique imagery), reconstructed into 3D data using the same workflow. The intent was to establish a visual and numerical expression of structure deterioration rate, that could be used as a starting point for further research into materials to be used in conservation - and indeed into the resilience of Neolithic structure materials when exposed to the elements anew.

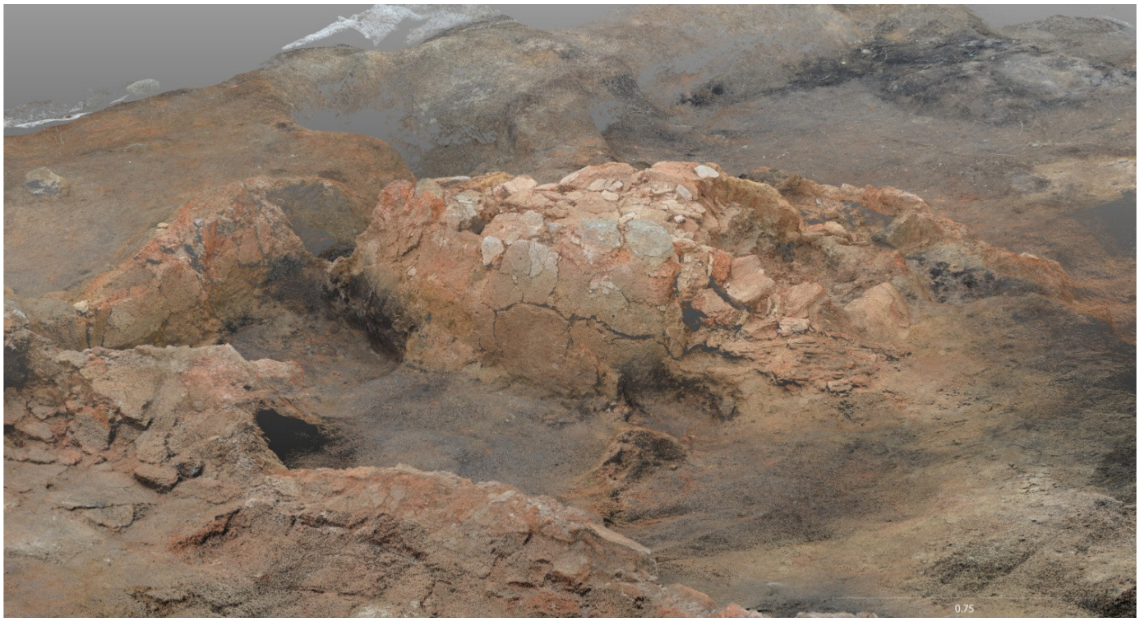

Figure 3: Point cloud view of the oven inside 01/06

The product of interest was a dense point cloud with a little more than 170 mil. points. The visual inspection showed little outlier results, due to limitations imposed on number of detections needed for reconstructed point to become valid. These were filtered out after which areas of interest were picked and separated for further study. The choice was made to use photos shot under overcast lightning conditions to avoid high dynamic range of imagery collected under intense sunlight; these are also useable but the potential chance for poor reconstruction and non-uniform lightning over the feature is higher, which would leave traces on other products (ortophoto, DEM), although, there are possibilities for using them in combination.

For comparison, the 2015 set is composed of 306 photos, while year 2006 set comprises of 55 photos and cover the same, even bit larger area. This difference is due to the fact that, at the time, documentation workflows were planned out in accordance with the necessary conditions for creating a photomosaic out of a limited number of images, each individually referenced, and mosaicked - these needed only a small overlap to work, whilst good overlap is a must when doing SFM acquisition. Thusly, this dataset (2006) has provided us with only a portion of the feature reconstructed to match with, with numerous gaps (Figure 4), however, enough to compute elevation differences in certain segments.

Both sets were georeferenced using Leica TCR307 total station measurements, prior to dense cloud reconstruction, using local grid of relative coordinates. After the reconstruction a mesh surface out of 2006 data, which represented starting point of deterioration process was created, to be used as reference model against which we tested the new data from 2015.

Terestrial Laser Scanning

Beside the photogrammetric survey, active sensor method of 3D measurement was performed on structure 01/06 - terrestrial laser scanning using FARO Focus 3D 120S. This model represent a mid-range laser scanner with scanning range from 0.3 to 120 meters, infrared laser beam at 935 nm wavelength and average noise range of scan data at 2-3 mm. The structure was scanned from 9 positions, in 0.036° scanning step which resulted in data set density of 7mm on 10m, but due to the fact that it was scanned at close range from overlapping positions, the density of produced cloud point is notably higher. Total number of 18 million points in the processed 3D model is colored by internal camera acquired images.

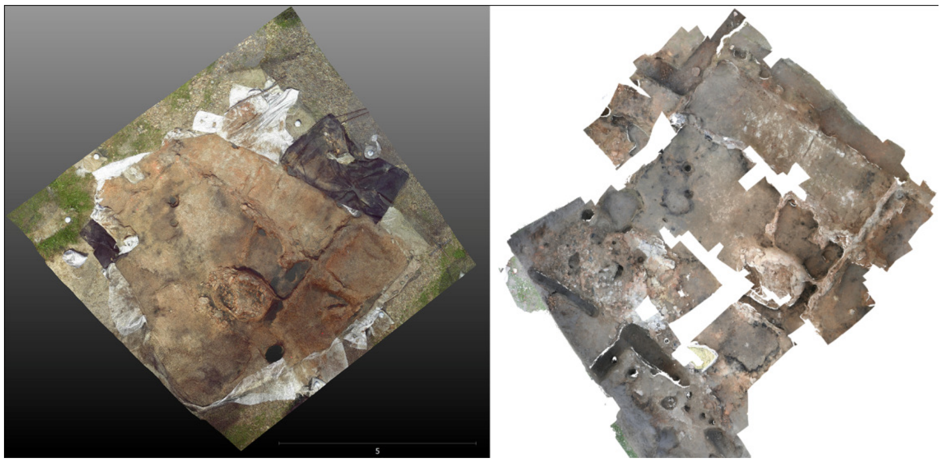

Figure 4: Left - overview of FARO 3D scan data - whole extent of the uncovered household, right - percentage of SFM reconstructed household state from 2006

The characteristics of the merged 3D data, e.g. the point cloud, created with TLS are as follows: it is visible that the point cloud is not of regular density - the points are measured in radial steps from different positions, and even with the elimination of duplicates, the generated point cloud contains both areas with high density of data and those with sparse data. This is the consequence of the complex geometry of earthen remains recorded. Also a small amount of outlier noise in the point cloud (points which obviously do not belong to measured surfaces) and stray points at model edges, all the result of laser beam splitting on contact, are noticable. The recorded information level is more than sufficient, because the 18 million points on roughly -10m^{2}area result in a resolution of 3D model of 180 point per cm². The color of the points represents natural colors, but in some places variation in exposure levels can be seen, due to overlapping of the scans taken from different positions with different camera calibration parameters. The reliability of the point position is high, with the error range of 3mm. Likewise, the speed of acquisition is relatively high as well, compared to other methods of 3D measurement (scanning time was around 10 minutes per position, so the acquisition of all data was finished in less than 2 hours).

Computer processing of scanned data to generate the point cloud took one working day. A convenient fact is also that, using the scanner's proprietary software, panoramic measurable view-sets of scans and the whole scan project can be browsed, and shared through web services.

Examining the overall completeness of the data capture, it stands out that existing post holes have been almost left out from the recording. This is due to the fact that the scanner has a certain maximum angle in which it can take measurements - being placed on a tripod, surfaces next to the scanner, or positioned under inconvenient angle compared to the path of the laser measurement, are ignored from 3D model (Figure 4).

Discussion

At present situation it is not expected that 01/06 will be able to stay indefinitely in this place - it would require that the area is excluded from future excavations, and placed in more protective conditions, possibly presented to the public. Images and 3D scan data from 2015 created a sort of "ground zero" recording of the situation, so whatever option is chosen for the future of it, it is expected that this data will provide a good basis into further works.

Being limited by the reconstructed area of the feature's state in 2006, which was (almost accidentally) suited for partial reconstruction, only a portion of the feature, the most northern room of 01/06 with partially recorded northern side of the house oven was chosen for the initial stage of comparison. Due to inadequate overlap in 2006 photographs, a significant proportion of the surfaces have been erroneously reconstructed, and are, at present, unsuitable for use.

In this area several features expected to be damaged by burial and post-burial stress; relatively thin and protruding daub walls, which were preserved to unusually high level, daub floor and oven walls, were found to be in a very good state of preservation.

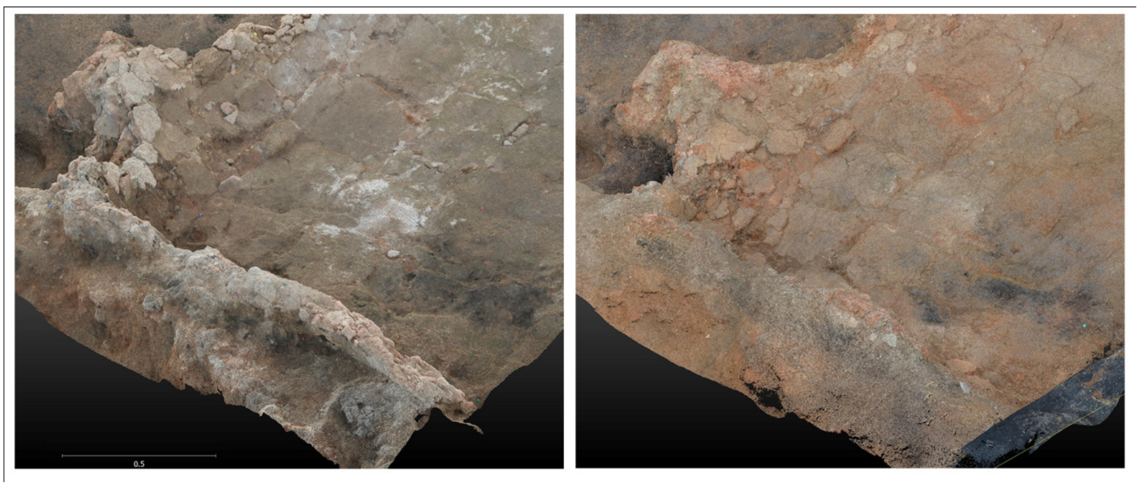

Figure 5: Left - surface created out of data from 2006, right - segment of point cloud used for comparison

Figure 5 illustrates mesh surface made out of points that were reconstructed with credibility, which was used to compute difference between the 2006 surface and the points recorded this season. These occupy the same space, being referenced in the same grid, and any differences between them would fall in to one of the 4 categories: 1. incomplete reconstruction , 2. erroneously reconstructed data, 3. structural failure/change of the feature under duress and 4. errors in georeferencing.

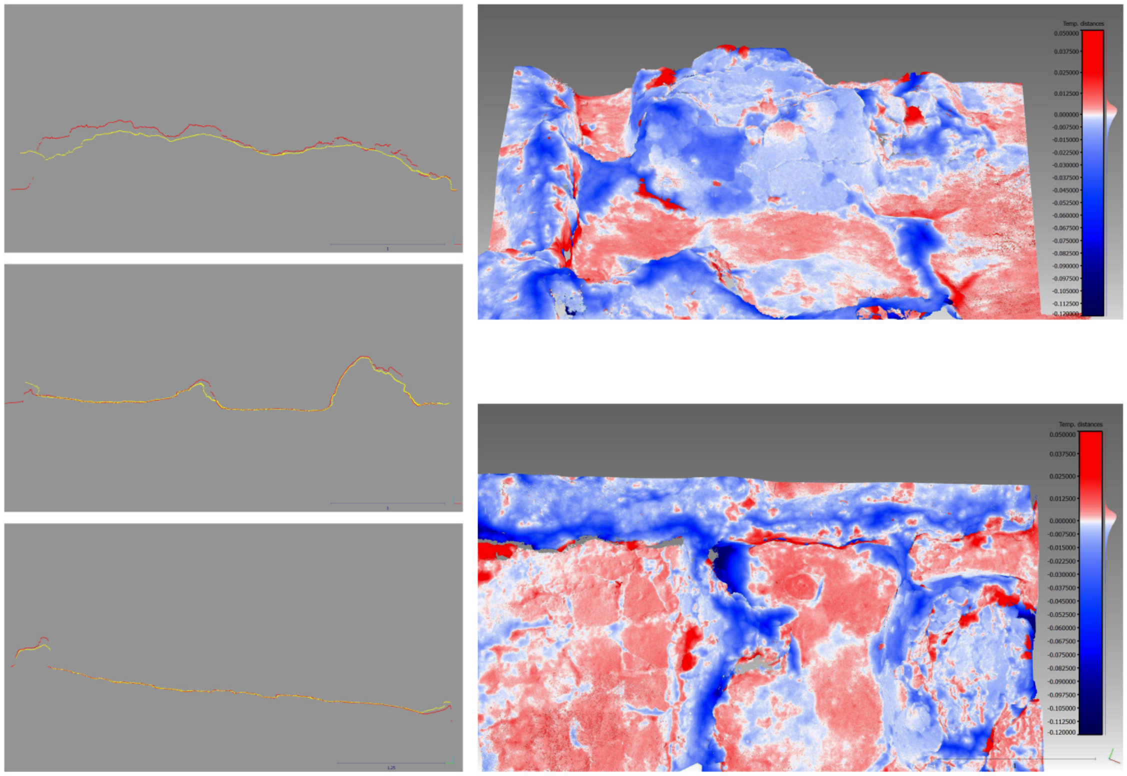

Figure 6: Upper left - profile section running through both datasets, eastern outer wall. In red are measurements from 2006, yellow 2015 middle left, profile section running through oven and inner wall, lower left - profile section of the northern room floor, upper right - view of the Neolithic oven with notable changes in structure in blue scale, lower right - same, view from the above.

The results show several changes in the state of the F01/06, and the most prominent is the structural damage on the outer and inner walls, which had very low survival chances to begin with (Figure 6). However, a large portion of these walls still stands and have not lost their form. Based on the data, the dome of the oven has been quite well preserved in height, and has a very low substance loss quota. Floors, which are very thick and well founded, show little difference compared to 2006 levels (Figure 6, lower left, also lower right in red).

Conclusion

What immediately falls into mind is that there is obviously a potential in revisiting photo archives of archaeological projects. Vinča project aspired to complete its database with photos taken on various account: we nearly have a touristic (not just needed) photo collection (9) of archaeological layers, spanning over the course of several years, that will almost certainly yield similarly acquired data, perhaps complemented with oblique or other appropriate imagery that makes up for a set. This can be a powerful resource to use to re-enact different stages of excavation, and think them through: what is important to realize is that apart from presentational purpose, there is always a "harvesting" part, where this type of data can be searched for additional information for prolonged periods.

This brings us to the intended use - the described undertaking tried presenting images from 2006 with a second chance for interpretation. To complete the study, active scan data needs to be cross checked with SFM, and archive imagery too; but also, a periodical assessment of F01/06 condition would be recommendable to continue, using methodology described here. With temporal resolution high enough more insight can be gained into understanding the best ways of protecting earthen structures, which do not always possess the luxury of staying away from modern infrastructural development, as it is the case with the protected area of Belo Brdo site.

Acknowledgements

Our study was performed under auspices and funding provided by CONPRA - Contributing to Preventive Archaeology (EC Maria Curie Program FP7-PEOPLE-2012-IAPP-324508 *Contributing the Preventive Archaeology: Innovativeness, Development and Presentation*; 2013- 2016 funded by: European Commission as a part of the work package (WP4) handled by project partner, Philosophical Faculty of Belgrade, Department of Archaeology.

The authors would also like to extend their gratitude to NFrames, for generously providing free access to SURE software.

References

[1] F. Remondino, S.F. El - Hakim, A. Gruen, Li Zhang, *Turning images into 3-D* Models, IEE Signal Processing Magazine (2008), 55–64.

[2] M. Dellepiane, et al., *Archeological excavation monitoring using dense stereo matching techniques*, Journal of Cultural Heritage (2012)

[3] J.McCarthy, *Multi - image photogrammetry as practical tool for cultural heritage survey and community engagement,* Journal of Archaeological Science, *43*(2014), 175–185.

[4] M. J. Westoby, et al., *Structure-from-Motion photogrammetry: A low-cost, effective tool for geoscience applications*, Geomorphology, 179(2012), 300–314.

[5] E. Nocerino, F. Menna, F.Remondino, *Accuracy of typical photogrammetric networks in cultural heritage 3D modeling projects*, ISPRS Archives, XL:5(2014), ISPRS Technical Commision V Symposium, 465–472.

[6] J. De Reu, et al., *Towards a three-dimensional cost-effective registration of the archaeological heritage*, Journal of Archaeological Science, 40(2013), 1108 –1121

[7] A.A.Sima, et. al., *Computer aided image geometry analysis and subset selection for optimizing texture quality in photorealistic models*, Computers & Geosciences, 52(2013), 281–291

[8] Wenzel, K., Rothermel, M., Haala, N. & Fritsch, D., *SURE – The ifp Software for Dense Image Matching*, Photogrammetric Week '13, 2013, Ed. D. Fritsch, Wichmann, Berlin/Offenbach, 59–70

[9] N. Snavely, S.M. Seltz, R. Szellski, *Modeling the World from Internet Photo Collections*, Int J Comput Vis, 2007