COMPARING 3D DIGITAL TECHNOLOGIES FOR ARCHAEOLOGICAL FIELDWORK DOCUMENTATION. THE CASE OF THESSALONIKI TOUMBA EXCAVATION, GREECE

Stamnas Anastasios[1], Kaimaris Dimitrios[2], Georgiadis Charalampos[3], Patias Petros[1]

1 School of Rural & Surveying Engineering, Aristotle University of Thessaloniki, Greece - tstamnas@yahoo.gr, patias@auth.gr

2 School of Spatial Planning and Development (Eng.), Aristotle University of Thessaloniki, Greece - kaimaris@auth.gr

3 School of Civil Engineering, Aristotle University of Thessaloniki, Greece - harrisg@civil.auth.gr

KEY WORDS: Aerial & Terrestrial Data Acquisition, U.A.V, Laser Scanning, Data Comparison, Cultural Heritage, Preservation.

ABSTRACT:

Nowadays, there are many methods and techniques for the documentation and the restoration of historic structures and historical artifacts that are commonly used due to their completeness, accuracy and fastness. The use of advanced 3D measurement technologies, by either using terrestrial or aerial means of acquiring digital data, has become an efficient and reliable documentation tool. Within this context, this study focuses on combining terrestrial laser scanning, unmanned aerial vehicle photogrammetry, close-range photogrammetry and topographic surveying, and comparing the associated digital data for archaeological fieldwork documentation. The data collected during the Thessaloniki Toumba Excavation (Greece) provided accurate digital surface models and photo-realistic three-dimensional outputs of archaeological trenches. The data elaboration enabled new inferences and knowledge to be gained through the implementation of advanced technologies in heritage documentation.

1. INTRODUCTION

Until now, many projects and applications for cultural heritage documentation have been realized using and combining terrestrial laser scanning (TLS), Unmanned Aerial Vehicle (UAV) photogrammetry, close-range photogrammetry (CRP) and topographic surveying. As far as it concerns the digital documentation of archaeological sites and artefacts, their three-dimensional photo-realistic models allow to document, manage and analyze the shape and the dimensions of the represented objects in terms of accuracy and resolution.

This study applied terrestrial laser scanning, UAV and close-range photogrammetry for the 3D digital documentation of the Thessaloniki Toumba Excavation (Greece). Point clouds of selected archaeological trenches, obtained through different methodologies (laser scanning, UAV and close-range photogrammetry) have been compared and combined in order to explore different aspects (e.g. the spatial accuracy of digital geometric data) concerning advanced technologies for acquisition and documentation of historical objects for preservation purposes. The results of this study are expected to contribute to the development of accurate 3D documentation and spatial analysis of cultural heritage sites.

The present project addressed similar challenges as experienced during projects such as the Upper Paleolithic Cave of Parpalló project in Spain (Lerma et al., 2010), the Chapel of the Kings in the Palencia Cathedral project in Spain (Jordá et al., 2011), as well as more recent works such as the Magoksa Temple project in the Republic of Korea (Hoon Jo et al., 2019) and the complex churches project in Georgia (Luhmann et al., 2019). The discussion to explore best approaches, methods and tools, is still in progress.

2. STUDY AREA: THE THESSALONIKI TOUMBA EXCAVATION

The Thessaloniki Toumba Excavation (Figure 1) is a research program of the School of History and Archaeology, the Aristotle University of Thessaloniki (AUTh), Greece. The excavation projects have brought to light significant findings and have contributed significantly to the progress of archaeological research (investigation of the various aspects of the prehistoric habitation in the area, of the social, political and economic structures and of their transformation within a long-standing prehistoric community etc.). These projects have also provided undergraduate and postgraduate students with extensive training in excavation methods.

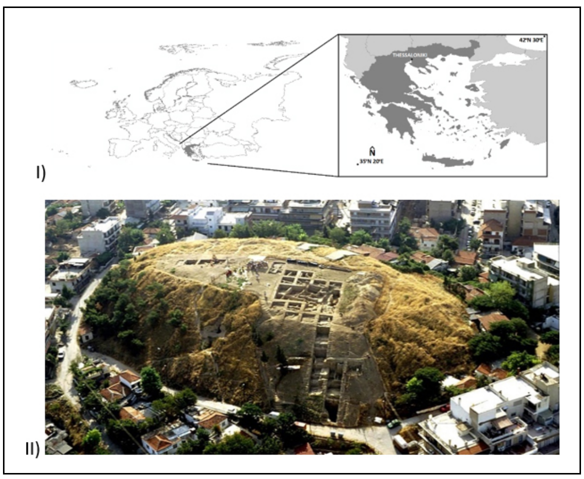

Figure 1. (I) Thessaloniki, located in Northern Greece, central Macedonia (Source: Google Earth) and (II) Thessaloniki Toumba Excavation as seen from above (Source: http://toumba.web.auth.gr).

Furthermore, the collaboration with other departments of the AUTh, such as the Department of Cadastre, Photogrammetry and Cartography, School of Rural and Surveying Engineering, allowed the application of a great number of up-to-date methods, practices and techniques such as the ones described here. The study area of the present project consists of 3 archaeological trenches during the first day of the measurements and of 4 archaeological trenches during the second day.

3. METHODOLOGY

The whole process can be divided into 3 main stages: (I) the data acquisition process, (II) the data processing and (III) the data comparison (Figure 2). The first stage (I), the data acquisition process, comprises of different means of collecting digital data such as the topographic survey campaign, the terrestrial laser scanning campaign, the UAV and the terrestrial photography campaign. The second stage (II), the data processing, consists of the data elaboration and the production of 3D point clouds and 3D aerial and terrestrial models. The third stage (III), the data comparison, involves the comparison of 3D point clouds derived from the terrestrial scanning campaign and the 3D models derived from the UAV and terrestrial photography campaign. The above comparison mainly determined how aerial and terrestrial data was collected during the second day of the excavation activity documentation.

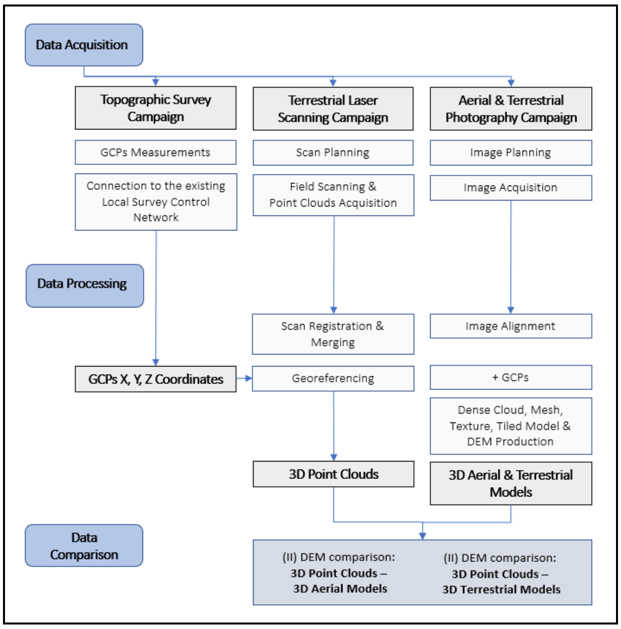

Figure 2. Overall workflow of the presented methodology.

4. ANALYSIS OF FIELD MEASUREMENTS & DATA ACQUISITION PROCESS

Within the framework of the Thessaloniki Toumba Excavation (Figure 1), 2 terrestrial laser scanning, image acquisition and topographic survey campaigns took place in July 2019 (4 & 19/7/2019). Additionally, a UAV image acquisition campaign also took place the first day of the fieldwork (4/7/2019) in order to document the archaeological site. Based on the evaluation of the results of the first campaign it was obvious that the achieved accuracy of the close-range approach was better than the one achieved using UAV imagery. As a result, it was decided not to acquire any UAV imagery during the second campaign.

4.1 Topographic survey campaign

During the topographic survey campaign, 36 (first campaign) and 42 (second campaign) Ground Control Points (GCPs) have been measured. Significant changes have been observed due to excavation work between the two topographic survey campaigns such as the integration of two trenches (trenches 2 and 3), the excavation of a new trench (trench 4) etc. The GCPs have been distributed properly in order to cover all the study area, both the 3 archaeological trenches (Figure 4) during the first campaign and the 4 archaeological trenches (Figure 5) during the second campaign, and to be easily identified in all images (terrestrial and aerial). The coordinates of these points have been measured with traditional surveying methods, using the reflectorless TCR305 Leica total station with an accuracy of 0.5cm in both planimetry and height. These measurements have been connected to the existing local coordinate system network of the Thessaloniki Toumba Excavation.

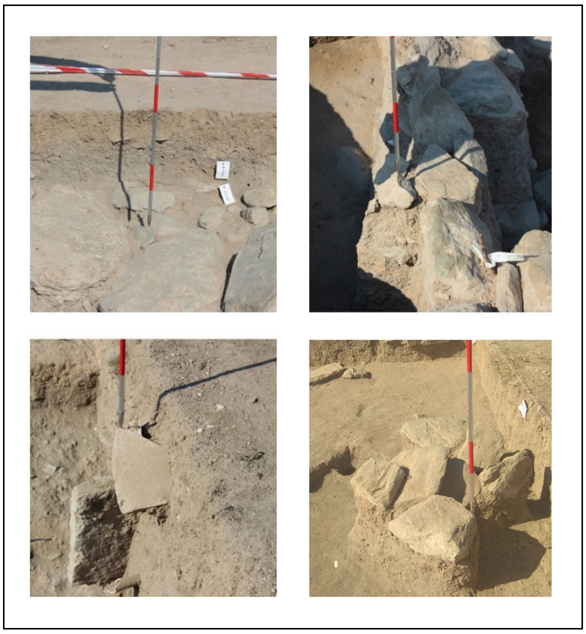

Figure 3. Selected Ground Control Points measured during the topographic survey campaign.

4.2 Terrestrial laser scanning campaign

During the data acquisition process, the "Faro focus 3d X 120" laser scanner (Table 1) was used for Digital Surface Model (DSM) collection and data were collected from 25 stations in order to capture the selected archaeological trenches of the Toumba excavation (Figure 4 & 5).

Technical specifications of the "Faro focus 3d X 120" laser scanner	
Distance accuracy	up to ±2mm
Dynamic range	from 0.6m up to 130m
Noise reduction	50,00%

Table 1. Technical specifications of the "Faro focus 3d X 120" laser scanner.

https://doi.org/10.5194/isprs-archives-XLVI-M-1-2021-713-2021

The data acquisition process lasted for 2 days (measurements from 10 stations during the first campaign and measurements from 15 stations during the second campaign). During the fieldwork, field measurements were organized, a methodology for conducting fieldworks was established and the following steps were taken into account: (I) Delimitation of scan area, (II) Designing of sketches illustrating the positioning of the 3d laser scanner and (III) Selection of initial settings of the 3d laser scanner (quality of scanning, scan resolution, scanning in color etc.). The scans were acquired with a resolution 0.006 m in a distance of 10 m.

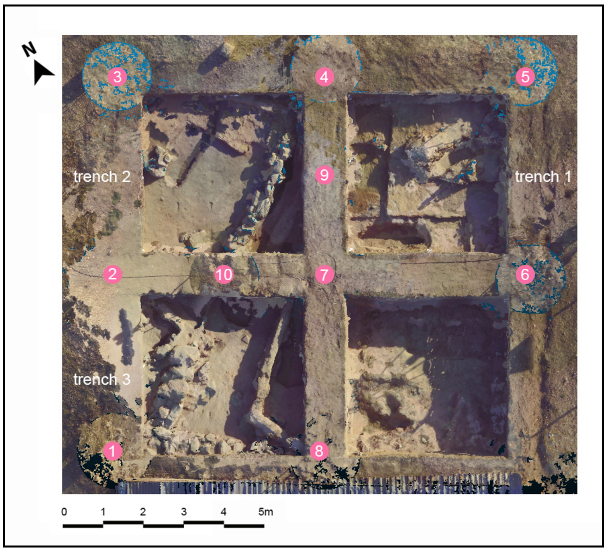

Figure 4. The positioning of the laser scanner during the first day of the fieldwork (10 measurements).

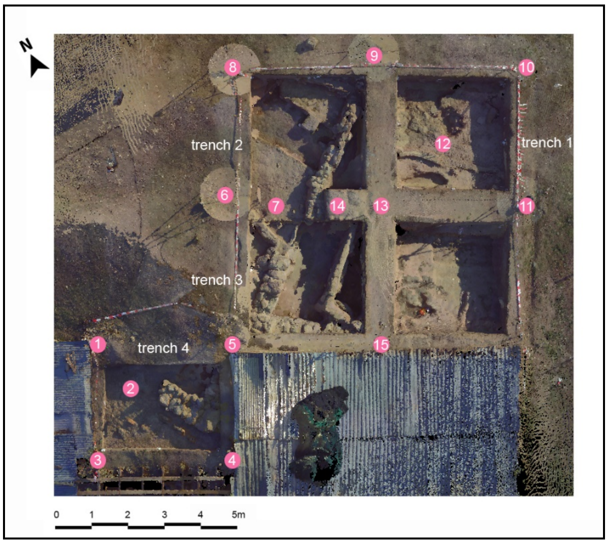

Figure 5. The positioning of the laser scanner during the second day of the fieldwork (15 measurements).

4.3 Aerial UAV photography campaign

For the photogrammetric documentation of the selected archaeological trenches of Toumba excavation an autonomous UAV (Figure 6), equipped with a pair of sensors, has been used. UAV flight was done manually and images were taken every 1sec in order to achieve a dense overlap between images. The flight altitude was initially planned to be fixed between 8 and 10m. The sensors mounted to the UAV were the Canon EOS 1200D (DSLR 18 Mp, with CMOS sensor 22.3 mm x 14.9 mm, Canon lens EF-S 17–85 mm f/4–5.6 IS USM, focal length 17–85 mm and diaphragm opening range 4-5.6) and the Sequoia+ Parrot (including 4 multispectral sensors featuring green, red, red edge and near-infrared bands, 1.2 Mp and a 16 Mp RGB sensor). The two cameras were mounted on a special platform to eliminate the vibrations of the UAV, able to rotate 360 degrees in horizontal and vertical direction. In the end, images with 80% coverage per image and 3 strips with 60% coverage per strip (for both sensors) were selected for further processing. Furthermore, as it emerged from the process of photogrammetric processing of the images, the average flight altitude was 9m (i.e., small variations from 8.6 to 9.4m).

Figure 6. The autonomous UAV system during the UAV photography campaign.

5. DATA PROCESSING

5.1 Laser scanner data processing

The laser scanner data processing can be subdivided into 3 main stages (Figure 7): (I) Scan points Colorization using the Faro Scene software, (II) Scan points Registration, Merging and Model Export using the Geomagic Studio software and (III) Model Georeferencing using the PolyWorks Inspector software. The result of the Model Georeferencing using the PolyWorks Inspector software was found to be acceptable for both the 10 stations measurements during the first day and 15 stations measurements during the second day of the fieldwork (Table 2).

Table 2 shows the Model Georeferencing results for all trenches at the same time (1, 2 & 3) during the first campaign (4/7/2019) and for all trenches at the same time (1, 2, 3 & 4) during the second campaign (19/7/2019). The distribution of the Ground Control Points (9 out of 36 GCPs during the first day and 6 out of 42 GCPs the second day of the field work) was done in such a way that they were all well distributed throughout the study area.

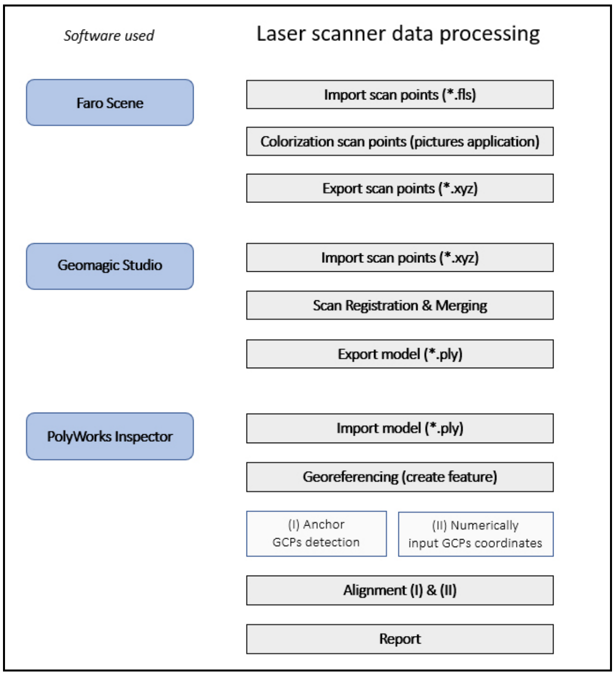

Figure 7. Overall workflow of the laser scanner data processing.

Model Georeferencing results		
Day of field work	1st (4/7/2019)	2nd (19/7/2019)
Trenches	1, 2 & 3	1, 2, 3 & 4
Number of scans	10	15
Number of GCPs	9	8
Maximum Error (m)	0.034	0.032
Minimum Error (m)	0.009	0.020
Mean Error (m)	0.024	0.029
Standard Deviation (m)	0.008	0.006

Table 2. Model Georeferencing results using the PolyWorks Inspector software.

5.2 Aerial and terrestrial image processing

5.2.1 The first campaign

The AgiSoft PhotoScan software has been used for both the terrestrial and aerial image processing (Figures 8 & 9) of the first campaign (4/7/2019). The AgiSoft PhotoScan software is a widely used Structure-from-Motion (SfM) program, which is used in various applications. The general steps that one has to follow are: (I) Adding images to the project, (II) Aligning the images, (III) Building a dense point-cloud, (IV) Creating a 3D surface mesh from the point-cloud and (V) Creating a texture for the mesh. Table 3 shows the number of images, the GCPs, the error (m), the ground sample distance (GSD) in orthoimages and the number of points in point clouds during the Agisoft Photoscan image processing of the first day (4/7/2019) of the fieldwork.

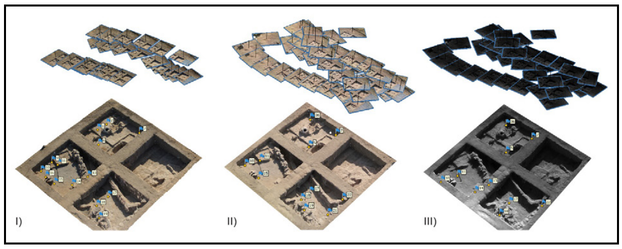

Figure 8. Overview of the GCPs and the aerial image data after the image orientation (4/7/2019) in AgiSoft PhotoScan software of the 3 archaeological trenches: (I) DSLR Canon EOS 1200D, (II) Sequoia RGB Parrot and (III) Sequoia MultiSpectral Parrot.

Figure 9. Overview of the GCPs and the terrestrial image data (DSLR Canon EOS 1200D, 4/7/2019) after the image orientation in AgiSoft PhotoScan software of the: (I) first, (II) second, (III) third archaeological trench.

AgiSoft PhotoScan image processing (4/7/2019)						
Images	Photographic camera	Number of images	Number of GCPs	Error (m)	GSD (m)	Number of points
Aerial						
trenches 1,2,3	DSLR Canon EOS 1200D	22	12	0.024	0.002	18.660.763
trenches 1,2,3	Sequoia RGB Parrot	39	11	0.049	0.003	27.694.786
trenches 1,2,3	Sequoia MultiSpectral Parrot	39x4	8	0.021	0.008	1.490.995
Terrestrial						
trench 1	DSLR Canon EOS 1200D	28	6	0.005	0.0007	71.975.285
trench 2	DSLR Canon EOS 1200D	37	6	0.008	0.0007	75.027.183
trench 3	DSLR Canon EOS 1200D	66	8	0.006	0.0005	118.186.650

Table 3. Number of images, GCPs and Error (m) during the Agisoft Photoscan image processing (4/7/2019).

5.2.2 The second campaign

After having reached a satisfactory accuracy using terrestrial imagery during the first campaign (4/7/2019), UAV image acquisition was not considered necessary for the second campaign (19/7/2019). The AgiSoft PhotoScan software has been used, as well, for the terrestrial image processing (Figure 10) of the second campaign. Table 4 shows the number of images, the GCPs, the error (m), the ground sample distance (GSD) in images and the number of points in point clouds during the Agisoft Photoscan image processing of the second campaign (19/7/2019).

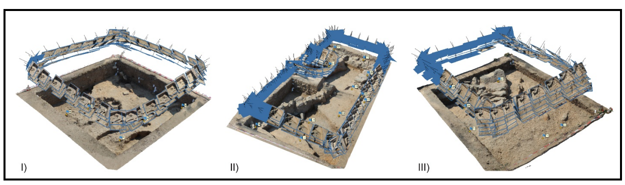

Figure 10. Overview of the GCPs and the terrestrial image data (DSLR Canon EOS 1200D, 19/7/2019) after the image orientation in AgiSoft PhotoScan software of the: (I) first, (II) second and third, (III) forth archaeological trench.

https://doi.org/10.5194/isprs-archives-XLVI-M-1-2021-713-2021

AgiSoft PhotoScan image processing (19/7/2019)						
Images	Photographic camera	Number of images	Number of GCPs	Error (m)	GSD (m)	Number of points
Terrestrial						
trench 1	DSLR Canon EOS 1200D	107	5	0.008	0.0006	34.754.119
trench 2&3	DSLR Canon EOS 1200D	257	11	0.010	0.0005	87.923.227
trench 4	DSLR Canon EOS 1200D	150	6	0.003	0.0004	50.010.955

Table 4. Number of images, GCPs and Error (m) during the Agisoft Photoscan image processing (19/7/2019).

6. DATA COMPARISON

The DEM comparison was performed using the ERDAS IMADINE software while using the same reference system. The referenced model in all cases was the 3D model derived from the laser scanner campaign and the aligned model was the 3D model derived from close-range photogrammetry using the AgiSoft PhotoScan software. The ERDAS IMADINE software made it possible to compare separately the 3D models of each trench (Table 5, 6 & 7) while creating monochromatic renderings of the “difference image” resulting from the DEM comparison of the archaeological trenches (Figure 11, 12 & 13). The cell size of these created “difference images” of the archaeological trenches was 0.010m, corresponding to survey accuracy.

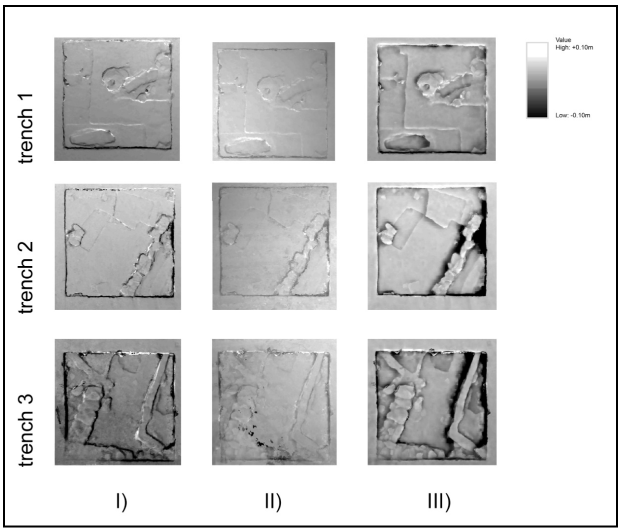

Figure 11. Monochromatic rendering of the “difference image” resulting from the 3D model comparison (4/7/2019) between (I) laser scanner and DSLR Canon EOS 1200D, (II) laser scanner and aerial Sequoia RGB Parrot and (III) laser scanner and aerial Sequoia MultiSpectral of the 3 archaeological trenches.

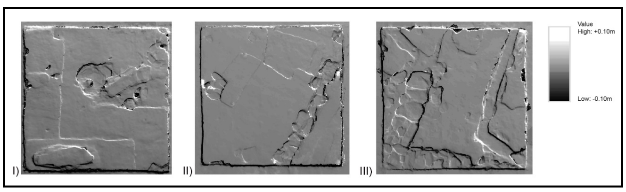

Figure 12. Monochromatic rendering of the “difference image” resulting from the 3D model comparison (4/7/2019) between laser scanner and terrestrial DSLR Canon EOS 1200D of the: (I) first, (II) second, (III) third archaeological trench.

3D model comparison between laser scanner & aerial image data - 4/7/2019			
cell size: 0.010m			
	RMSE	Abs. Mean	Std. Dev.
laser scanner – aerial DSLR Canon EOS 1200D			
trench 1	0.030	0.011	0.030
trench 2	0.060	0.022	0.061
trench 3	0.075	0.035	0.078
laser scanner – aerial Sequoia RGB Parrot			
trench 1	0.085	0.070	0.079
trench 2	0.084	0.057	0.084
trench 3	0.099	0.055	0.099
laser scanner – aerial Sequoia MultiSpectral Parrot			
trench 1	0.052	0.030	0.047
trench 2	0.108	0.053	0.099
trench 3	0.111	0.054	0.110

Table 5. 3D model comparison between laser scanner and aerial image data of the first campaign (4/7/2019).

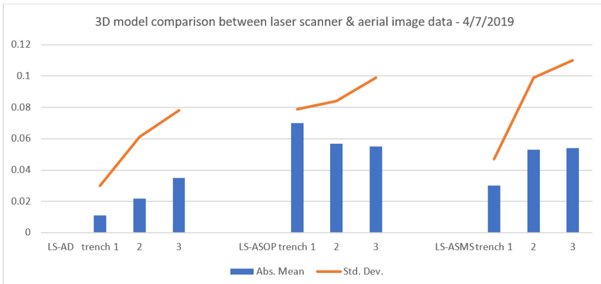

Chart 1. 3D model comparison between laser scanner and aerial image data during the first day of the fieldwork (4/7/2019). LS-AD: Laser Scanner vs Aerial DSLR, LS-ASOP: Laser Scanner vs Aerial Sequoia Optical, LS-ASMS: Laser Scanner vs Aerial Sequoia MS.

3D model comparison between laser scanner & terrestrial image data - 4/7/2019			
cell size: 0.010m			
	RMSE	Abs. Mean	Std. Dev.
laser scanner – terrestrial DSLR Canon EOS 1200D: trench 1	0.026	0.008	0.026
laser scanner – terrestrial DSLR Canon EOS 1200D: trench 2	0.050	0.014	0.050
laser scanner – terrestrial DSLR Canon EOS 1200D: trench 3	0.038	0.010	0.038

Table 6. 3D model comparison between laser scanner and terrestrial image data of the first day of the fieldwork (4/7/2019).

https://doi.org/10.5194/isprs-archives-XLVI-M-1-2021-713-2021

That being said, it is important to note that the comparison of the point cloud data of the second campaign of the excavation activity (laser scanning and terrestrial photography campaign) repeat and verify the corresponding data of the first day (Table 6 & 7). For the sake of completeness of the documentation of the excavation activity, it was considered essential to be presented here, as major conclusions have been drawn in the context of archaeological research, through the ongoing monitoring of the excavation.

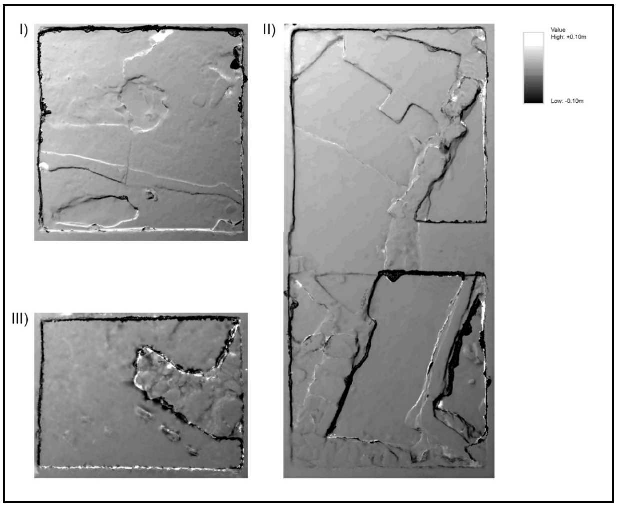

Figure 13. Monochromatic rendering of the "difference image" resulting from the 3D model comparison (19/7/2019) between laser scanner and terrestrial DSLR Canon EOS 1200D of the: (I) first, (II) second and third, (III) forth archaeological trench.

3D model comparison between laser scanner & terrestrial image data - 19/7/2019			
cell size: 0.010m			
	RMSE	Abs. Mean	Std. Dev.
laser scanner – terrestrial DSLR Canon EOS 1200D: trench 1	0.055	0.013	0.055
laser scanner – terrestrial DSLR Canon EOS 1200D: trench 2&3	0.052	0.018	0.050
laser scanner – terrestrial DSLR Canon EOS 1200D: trench 4	0.064	0.017	0.063

Table 7. 3D model comparison between laser scanner and terrestrial image data of the second day of the fieldwork (19/7/2019).

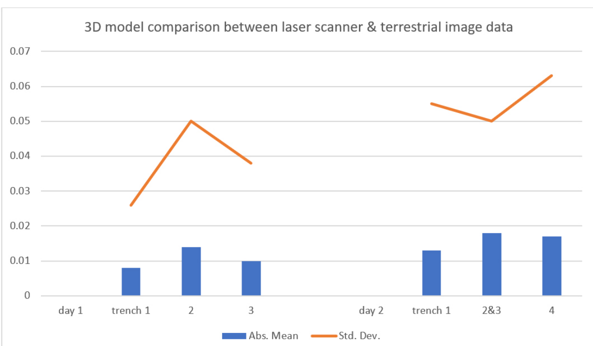

Chart 2. 3D model comparison between laser scanner and terrestrial image data during the first day (4/7/2019) and the second day (19/7/2019) of the fieldwork.

7. CONCLUSIONS

In conclusion, the point cloud data derived from the UAV photography campaign contained a significant number of holes, deformations and gaps compared to the point cloud data derived from the terrestrial laser scanning campaign due to the incomplete coverage of the study area, especially of the second and third archaeological trenches (Figure 14). The presence of these holes, deformations and gaps mainly in the vertical sides of the archaeological trenches in the point cloud data derived from the UAV photography campaign, is the main reason for their differentiation from the corresponding point clouds derived from the terrestrial laser scanning campaign (Table 5).

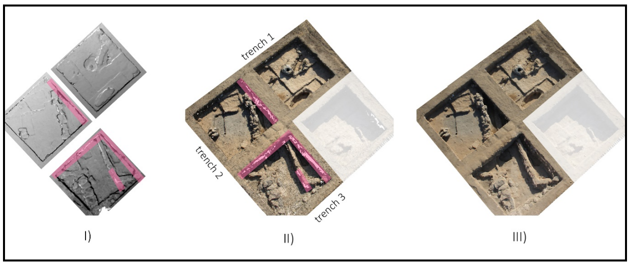

Figure 14. The presence of holes, deformations and gaps (marked in pink) in the vertical slopes of the archaeological trenches in (I) monochromatic rendering of the "difference image" resulting from the 3D model comparison (4/7/2019) between laser scanner and aerial DSLR Canon EOS 1200D, (II) the dense cloud and (III) the textured model in AgiSoft PhotoScan software of the 3 archaeological trenches.

The 3D model comparison between the laser scanning data and the image data showed that there are larger differences between the aerial image data than the terrestrial image data (Table 5 and 6). The smaller variations observed in the 3D model comparison, that is, the terrestrial image data than the aerial image data, led to the decision not to repeat the aerial measurements on the second campaign of the excavation activity documentation. Regarding the aerial image data, greater variations are observed in data derived from the Sequoia MultiSpectral Parrot and the Sequoia RGB Parrot and less in data derived from the DSLR Canon EOS 1200D. As far as it concerns the terrestrial image data, by removing the vertical sides of the trenches (Figure 15), the results of the 3D model comparison between laser scanning data and image data are even better (Table 8).

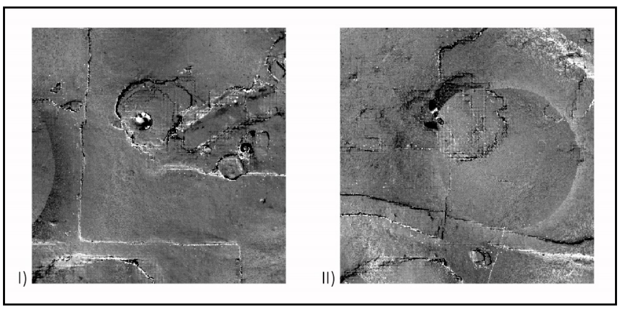

Figure 15. Detail of the monochromatic rendering of the "difference image" resulting from the 3D model comparison between laser scanner and terrestrial DSLR Canon EOS 1200D of the first archaeological trench (apart of the vertical sides) during: (I) the first campaign (4/7/2019) and (II) the second campaign (19/7/2019) of the documentation of the excavation activity.

3D model comparison between laser scanner & terrestrial image data of the first trench			
cell size: 0.010m			
	RMSE	*Abs. Mean*	*Std. Dev.*
first day (4/7/2019)	*0.012*	*0.004*	*0.012*
second day (19/7/2019)	*0.007*	*0.003*	*0.007*

Table 8. 3D model comparison between laser scanner and terrestrial image data of the first and the second day of the documentation of the excavation activity of the first trench.

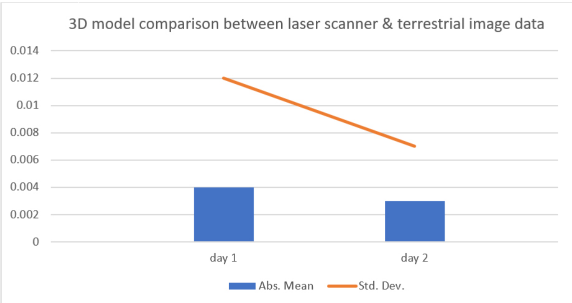

Chart 3. 3D model comparison between laser scanner and terrestrial image data of the first archaeological trench (apart of the vertical sides) during the first day (4/7/2019) and the second day (19/7/2019) of the fieldwork.

In any case, the outcomes of this research reveal that both close-range photogrammetry and laser scanning are successful and provide reliable data. The outcomes of these techniques represent excellent quality and accurate three-dimensional models. Moreover, close-range photogrammetry and laser scanning are suitable techniques for heritage documentation overcoming their individual limits. As a result, these two techniques should be considered complementary (coverage and mapping of remote or inaccessible areas, measurements of different scales and corresponding accuracy of the final products, calculation of height discontinuities, creation and comparison of hybrid cartographic products etc.) rather than competitive.

ACKNOWLEDGEMENTS

This paper has been accomplished on behalf of the project SMART EYE: Development of a prototype for smart visualization of invisible antiquities. The project is running under the framework of the Operational Program Competitiveness, Entrepreneurship and Innovation 2014-2020 (EPAnEK), Special Actions "Aquaculture" - "Industrial Materials" - "Open Innovation in Culture", T6YBΠ-00023.
The authors want to thank prof. S. Andreou (School of History and Archaeology, AUTh) who had the scientific direction of the excavation research of the Thessaloniki Toumba Excavation which takes place every year since 1984.

REFERENCES

Böhm J., Haala N., 2005. Efficient integration of aerial and terrestrial laser data for virtual city modeling using lasermaps, ISPRS WG III/3, III/4, V/3 Workshop "Laser scanning 2005", September 12-14, Enschede, the Netherlands, 192-197.

Burdziakowski P., Tysiac P., 2019. Combined close range photogrammetry and terrestrial laser scanning for ship hull modelling, Geosciences, 9, 242, 1-16.

Galeazzi, F., 2016. Towards the definition of best 3D practices in archaeology: Assessing 3D documentation techniques for intra-site data recording, Journal of Cultural Heritage, 17, 159–169.

Hoon Jo Y., Hong S., 2019. Three-dimensional digital documentation of cultural heritage site based on the convergence of terrestrial laser scanning and Unmanned Aerial Vehicle photogrammetry, ISPRS International Journal of Geo-Information, 8, 53, 1-14.

Jordá, F., Navarro, S., Perez, A., Cachero, R., Lopez, D., Lerma, J.L., 2011. Close range photogrammetry and terrestrial laser scanning: High resolution texturized 3D model of the Chapel of the Kings in the Palencia Cathedral as a case study, XXIIIrd International CIPA Symposium, Prague, Czech Republic.

Kimball J.L. J., 2016. 3D Delineation: A modernisation of drawing methodology for field archaeology, Archaeopress Publishing Ltd, Oxford, United Kingdom, 1-682.

Kuçak R.A., Kiliç F., Kisa A., 2016. Analysis of terrestrial laser scanning and photogrammetry data for documentation of historical artifacts, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLII-2/W1, 2016 3rd International GeoAdvances Workshop, Istanbul, Turkey, 155-158.

Lerma J.L., Navarro S., Lopez M. Cab., Cabrelles M., Villaverde V., 2010. 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 37, 499–507.

Liang, H.; Li, W.; Lai, S.; Zhu, L.; Jiang, W.; Zhang, Q., 2018. The integration of terrestrial laser scanning and terrestrial and unmanned aerial vehicle digital photogrammetry for the documentation of Chinese classical gardens - A case study of Huanxiu Shanzhuang, Suzhou, China, Journal of Cultural Heritage, 33, 222–230.

Luhmann T., Chizhova M., Gorkovchuk D., Hastedt H., Chachava N., Lekveishvili N., 2019. Combination of terrestrial laser scanning, UAV and close-range photogrammetry for 3d reconstruction of complex churches in Georgia, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLII-2/W11, GEORES 2019 – 2nd International Conference of Geomatics and Restoration, Milan, Italy, 753-761.

Moon, D., Chung, S., Kwon, S., Seo, J., Shin, J., 2019. Comparison and utilization of point cloud generated from photogrammetry and laser scanning: 3D world model for smart heavy equipment planning, Automation in Construction 98, 322-331.

Patias, P., Georgoula, O., Kaimaris, D., Georgiadis, Ch., Stylianidis, S., Stamnas, A., 2008. 3D Mapping using Model Helicopter and Laser Scanning: case study activities of the laboratory of Photogrammetry and Remote Sensing, AUTh. 14th International Conference on Virtual Systems and Multimedia (VSMM) dedicated to Cultural Heritage, Nicosia, Cyprus, 1-5.

Patias P., Kaimaris D., Georgiadis Ch., Stamnas A., Antoniadis D., Papadimitrakis D., 2013. 3D mapping of Cultural Heritage: Special problems and best practices in extreme case-studies, ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume II-5/W1, XXIV International CIPA Symposium, 2-6 September 2013, Strasbourg, France, 223-228.

Pérez, M., Agüera, F., Carvajal, F., 2013. Low Cost Surveying Using an Unmanned Aerial Vehicle, International Archives of Photogrammetry and Remote Sensing, XL-1/W2, Rostock, Germany, 311–315.

Peterson S., Lopez J., Munjy R., 2019. Comparison of UAV imagery-derived point cloud to terrestrial laser scanner point cloud, ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume IV-2/W5, 2019, ISPRS Geospatial Week 2019, Enschede, The Netherlands, 149-155.

Previtali M., Valente R., 2019. Archaeological documentation and data sharing: digital surveying and open data approach applied to archaeological fieldworks, Virtual Archaeology Review, 10(20): 17-27, 17-27.

Radović J., Pajić V., Popović D., Govedarica M., Milovanov S., Combining airborne and terrestrial laser scanning in preservation of cultural heritage, eLibrary of Mathematical Institute of the Serbian Academy of Sciences and Arts, 27-33.

Remondino, F., 2011. Heritage Recording and 3D Modeling with Photogrammetry and 3D Scanning, Remote Sensing, 3(6), 1104-1138.

Reznicek, J., Pavella, K., 2008. New low-cost 3D Scanning Techniques for Cultural Heritage Documentation, In Proceedings of the International Archives of Photogrammetry and Remote Sensing, XXXVI-B5, Beijing, China, 237-240.

Rüther H., Smit J., Kamamba D., 2012. A Comparison of close-range photogrammetry to terrestrial laser scanning for heritage documentation, South African Journal of Geomatics, Vol. 1, No. 2, 149-162.

Valente R., Brumana R., Oreni D., Banfi F., Barazzetti L., Previtali M., 2017. Object-oriented approach for 3d archaeological documentation, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLII-2/W5, 2017, 26th International CIPA Symposium 2017, Ottawa, Canada, 707-712.