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CONVENTIONAL OR AUTOMATED PHOTOGRAMMETRY FOR CULTURAL HERITAGE DOCUMENTATION?

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ABSTRACT:

During the past 15 years photogrammetric practice has experienced an unprecedented change by the influence of computer vision algorithms, which support an almost completely automated processing. It is widely acknowledged that this fact has “democratized” Photogrammetry a lot, in the sense that it has become almost everyone’s tool. However, this radical change has been met by scepticism by traditional photogrammetrists, who claim that such tools may lead to geometrically wrong and inaccurate results if not accompanied by thorough projection and error checks and evaluation of the correctness of results.
In this paper, the two approaches are briefly described on the basis of the geometric documentation of a cultural heritage funerary monument situated in the archaeological site of Messini in Southern Greece. An effort is made for highlighting the obvious advantages of each approach but also indicating their disadvantages. Applications, subject to different requirements and processing procedures are identified, rationalizing that conventional photogrammetric procedures still cannot be easily replaced.

1. INTRODUCTION

1.1 The archaeological site of Messini

The archaeological site of Messini is situated in the southern part of Peloponnese (Figure 1). The ancient city of Messini was founded in the winter of 370 BC-369 BC. by the Theban general Epaminondas, after his victory over the Spartans at the battle of Leuctra and his invasion of Laconia. Epaminondas freed Messinia from Spartan influence and chose the foothills of Mount Ithomi to build the capital of the liberated Messinians. It was built almost at the same time as the Arcadian Megalopolis, so that Sparta could be excluded from hostile states and stop its influence outside Laconia.

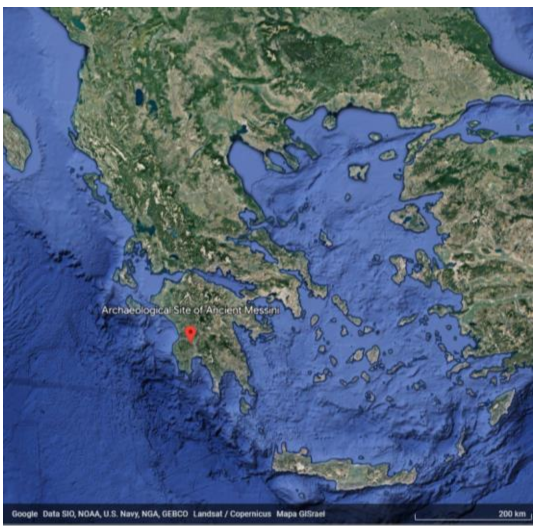


Figure 1. The position of the Archaeological site of Ancient Messini

The city remained the cultural centre (and perhaps also the political centre) of Messinia during Roman times and at least until the end of the 4th c. A.D. In 365 the great earthquake that struck the Eastern Mediterranean probably had significant effects on Messina as well. In 395 the invasion of Alaric's Goths is believed to have been the decisive blow to the city. Then its few inhabitants would begin to settle in safer settlements and the area would become deserted. The settlement continues as a large village with an important archaeological presence as well as historical references both during the Middle Byzantine period and during the Late Middle Ages.

In 1895, the Archaeological Society begun systematic excavations at the site under the direction of the archaeologist Themistocles Sophoulis, who later pursued a prominent career in politics. The excavating activity was resumed in 1909 and 1925 under the direction of G. Oikonomou. In 1957 Anastasios Orlandos who was at the time the Secretary of the Archaeological Society and member of the Academy of Athens took charge of the excavation project of Ancient Messini and worked until 1974. The excavation conducted by Anastasios Orlandos and his predecessors brought to light the greatest part of the building complex of the Asklepieion.

In 1986 the Board of the Archaeological Society assigned the direction of the excavation project to professor Petros Themelis. Excavations and work on the restoration of the extant monuments started in 1987 and continues to date showing significant progress. All the secular and sacred buildings which traveller Pausanias described in his work during his visit in 155-160 A.D., have been brought to light under P. Themelis’ direction (http://ancientmessene.gr/ ancientmessene.gr/index_en.html).

1.2 The K3 burial monument

For evaluating conventional and automated procedures for cultural heritage documentation a case study has been conducted using both approaches, namely stereoscopic restitution, and multi-image automated 3D modelling. The object of interest was the K3 burial monument of the Archaeological site of Messini

(Figure 2). The burial monument K3, in the Gymnasium of the ancient Messini, with the eight box-shaped tombs in its chamber, was built during the first quarter of the 3rd century B.C. to receive the eight bodies of deified deceased of a great financially and politically powerful family of the Messinian elite. Three women and five men were buried in K3, whose names, without the patronymics are written in the east side of the chamber, *Epikratia, Nikoxena, Nikicha, [- - - -]tinos, Agisistratos, Epikratis, [- - -]ippus* and *Xenippus*.

During the 1st century AD, the members of another Messinian, also aristocratic, family, that of Dionysios Aristomenous, used the same brilliant burial monument K3 of the 3rd c. BC, after some repair and rearrangement works of the graves of the chamber, for their burial. They have set up the marble statues of notable deified dead in front of the monument, on the pedestals of earlier bronze statues, thus practicing the favourite for that era practice of "recycling". This monument is unique in form, presenting several challenges to both procedures.

Figure 2. The K3 funerary Monument (© Authors)

It is an 8m high construction with a square masonry base up to 2.5m which is topped with a somewhat conical roof topped with a Corinthian capital, which bears an amphora. Initially, the monument was supposed to serve as the grave of an aristocratic Messinian family. A ramp leads to the interior chamber through the only entrance from the south. The monument was restored in 2018 by Prof. P. Themelis, responsible for the excavations in Ancient Messini since 1986 (Themelis, 2018).

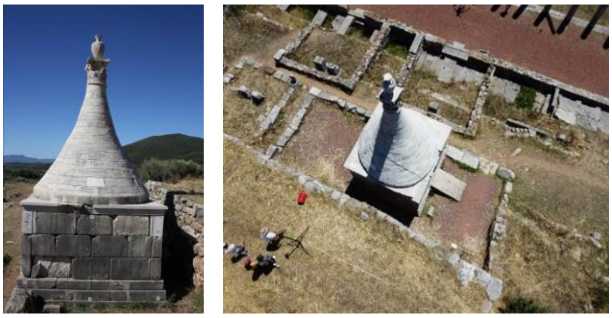
2. PREVIOUS WORK

There have been quite a few efforts to date aiming to evaluate traditional photogrammetric pipelines against automated methods. Obviously, automation has been so attractive, that "traditional" digital photogrammetric methods tend to be quickly discarded. However, mapping applications of extended areas still require the stereoscopic photogrammetric approach, which, no doubt, requires skill and experience. Therefore, it will still be part of Geomatics curricula worldwide.

As early as in 2012 (Skarlatos & Kyparissi, 2012), researchers were evaluating open source and commercial MVS systems based on standard photogrammetric algorithms, but also on image-based modelling solutions to TLS point clouds. Their findings point to the superiority of image-based procedures compared to laser scanning. In addition, classic photogrammetric solution was slightly inferior to the MVS approach. Westoby et al. (2012) reported on introducing the SfM method for DTM production and compared the results to terrestrial laser scans concluding that the automated approach freed them from the tedious determination of the coordinates of many GCP's. However, their conclusions are questionable as it seems they were less familiar with classical photogrammetric methods. Another study (Wenger, 2016) compared the techniques against airborne LiDAR point cloud again, in this case for the DTM production of an extended area. Contrary to the previous study, Wenger established that stereophotogrammetry produced results closer to the LiDAR point cloud, while the SfM/MVS automated approach gave very poor, practically useless outcomes. Finally, a more recent study (Li et al. 2018), recognising the weaknesses of both approaches, applied a combination of both, to produce the accurate DTM of an extended area. The researchers claim that they achieved better results than they would have by solely using LiDAR techniques.

3. DATA ACQUISITION

Data acquisition was simultaneously performed for both processing strategies, i.e., stereoscopic restitution and multi-image automated 3D modelling. The products to be delivered were orthophotos of the four external facades and a bird's eye orthophoto of the monument and the surrounding area, all of them at a scale of 1:50. For the terrestrial images two full frame DSLR camera were used with two different lenses, a 35mm and a 24mm lens. A special monopod reaching up to 8.50m was employed for lifting the camera at favourable vantage points for the stereoscopic coverage. For the mostly oblique aerial images a DJI Mavic Mini 2 was used from a flying height of 10-20 m. Thus, the achieved GSD's were in the range of 1-2.2mm for the DSLR and of 0.5-1.1mm for the UAV. For referencing the products several ground control points were surveyed on the facades, either pre-marked or natural detail points. For the western façade, a different image acquisition strategy was necessary, as the available space was less than 1m. Hence, for this façade a larger number of images in four strips was acquired. In total 118 images were taken with the DSLR and 87 images with the UAV and all of them were used for the SfM/MVS procedure. From these images 60 were used for the stereoscopic restitution of the four facades. In Figure 3 two sample images are presented.



(a) (b)

Figure 3. Sample images from the DSLR (a) and from the UAV (b) (© Authors)

Data acquisition for the terrestrial stereoscopic images lasted about a day and a half including the geodetic measurements for the GCP's. For the aerial images approximately half a day was necessary. The whole procedure was performed for students' training as part of an elective course of the 8th semester (Summer Field Course in Photogrammetry) offered by the School of Rural, Surveying and Geoinformatics Engineering of NTUA.

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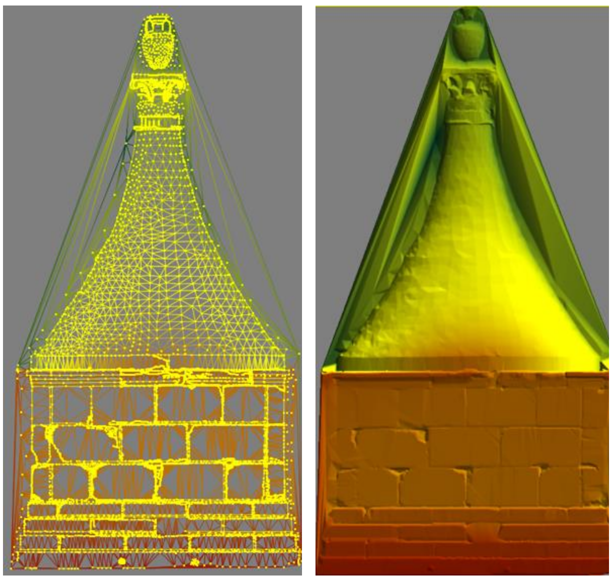
4. DATA PROCESSING

4.1 Digital Stereoscopic Photogrammetry

The processing of the terrestrial stereoscopic images was performed with the Digital Photogrammetric Workstation (DPW) Photomod v.7 lite edition by Racurs, which is an excellent educational tool for conventional photogrammetric restitutions (Yanniris et al. 2010). This involved orienting the image pairs for each façade in their own separate reference system to comply with the aerial photogrammetry case and adjusting them with phototriangulation. Then by stereoscopic observation via the anaglyph method the digital surface model points and break lines were collected (Figure 4 (a)). The software offers the possibility to observe the mesh triangles formed in stereo, in order to correct them if necessary. This has been a laborious procedure, which for the inexperienced students lasted for about three weeks. Normally this task would not last more than a week for all four facades. Subsequently, the four projection planes were determined and several orthophotos were produced from the oriented digital images. The most suitable orthophotos were then inserted into AutoCAD 2023 via their world files and the final orthophotomosaic was compiled (Figure 5). Eventual radiometric processing was performed where it was necessary.



(a) (b)

Figure 4. Triangular mesh and plotted surface details (a) and the corresponding DSM (b), both products of the stereo-photogrammetric procedure with Racurs Photomod.

4.2 Automated Photogrammetric Approach

For the automated workflow, UAV images together with the ones of DSLR camera were processed using the Agisoft Metashape v.1.7.5 software. All images formed one chunk and the processing, i.e., alignment, production of the dense cloud, the mesh and the textured model lasted for about 3 days using a powerful computer. The dense cloud was exported and processed in Geomagic Wrap® and subsequently reinserted into Metashape for the surface computation (Figure 6) and the orthophoto production. The orthophotos were produced by selecting the most suitable images for that purpose. Again, the orthophotomosaic (Figure 7) was imported in the AutoCAD 2023 environment.

Figure 5. Orthophotomosaic produced with the Racurs Photomod DPW

4.3 Comparative Analysis

The two processing methods led to similar results both acceptable. However, stereoscopic processing demands more effort both in terms of image acquisition and stereoscopic processing in cases of complex shaped objects, like the rounded part of the conical roof as well as the detail on top of it. As was expected, the edge of the conical roof demanded for more image pairs, which most probably would be hard to orient. Inclined stereopairs could be the obvious answer, but in this case the projection reference system would be inclined to the pair, thus making observations very hard. In terms of accuracy, stereoscopic processing met the specifications of the product scale.

Figure 6. The surface of the Eastern façade produced with Agisoft Metashape after re-moving noise and smoothing.

Figure 7. The orthophoto-mosaic of the Eastern façade produced with Agisoft Metashape

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Multi image processing produced more complete results as far as projected details are concerned. However, thorough checking of the automatically determined surface was necessary, in order to avoid wrong projections.

The two processing methods and their results are discussed and evaluated in detail pointing out the advantages and disadvantages of each one. For the sake of impartiality and uniformity, all comparisons and evaluations are referred to the Eastern façade of the K3 burial monument.

4.3.1 Triangulation results: The main photogrammetric procedure, irrespective of the method used is, of course, the orientation of the images in 3D space. Relative orientation determines the shape and is considered of utmost importance, while the triangulation is completed with the georeferencing of the photogrammetric network to the desired reference system determined by the GCP’s. In this case care was taken to keep the interior orientation parameters the same for both methods. Five images were used for both methods taken with a calibrated Canon EOS 6D DSLR full frame camera with 35mm prime lens. The resolution of the camera is 5472 x 3648 and its pixel pitch 6.66μm.
The time needed for the process of triangulating the 5 images by both methods is shown in Table 1. Triangulation includes setting up the project, inserting the images, performing interior orientation, determination of tie points, pointing of GCP’s and adjusting the network.

	Racurs Photomod	Agisoft Metashape
Tie Points + Orientation + DTM	6 hours	30 minutes

Table 1. Time necessary for the process of triangulation

In Tables 2 and 3 the exterior orientation parameters of the five images are shown as they were determined by the two methods. For the triangulation adjustments the same 12 GCP’s were used. 4 premarked ones and 8 natural detail points. In the case of the stereoscopic DPW (Racurs Photomod) 50 tie points were measured manually with stereoscopic pointing. In the case of the Agisoft Metashape, 9218 tie points were used, which were determined automatically by the software. It should be noted that all wrongly estimated points were deleted before the adjustment.

As may be deduced by the comparison of the two tables, the differences of the exterior orientation parameters are considered negligible, as they are less than 30mm in the linear parameters and much less than its equivalent in the rotation angles. Those differences are obviously caused by the large difference in the number of tie points, assuming that the adjustment algorithm is the same in both software.
Another comparison for the two triangulations is the residuals at the GCP’s. Unfortunately, due to the small size of the object and the limited time in the field, there were not any check points available for a more objective comparison. In Table 4 the Root Mean Square (RMS) errors are presented for both cases. It is obvious that in both cases the residuals are well within the scale tolerance (12.5mm), a lot better actually. However, there is a significant absolute difference in favour of the Agisoft Metashape adjustment. This is attributed to the large number of tie points, which increase the number of observation equations, thus achieving better fit to the known coordinates of the GCP’s.

RMS (m)	**X (m)**	**Y (m)**	**Z (m)**	**Exy**
Racurs Photomod	0.004	0.008	0.004	0.009
Agisoft Metashape	0.002	0.002	0.003	0.003

Table 4. Ground control point residuals (m):

Image	**Xo (m)**	**Yo (m)**	**Zo (m)**	**ω (deg)**	**φ (deg)**	**κ (deg)**
IMG_4534	1202.499	105.451	-738.118	0.0562	-1.1803	92.2314
IMG_4535	1203.991	105.477	-738.273	-0.3865	0.2866	92.8259
IMG_4536	1205.907	105.552	-738.435	-1.5186	-0.7981	91.9721
IMG_4538	1207.618	105.613	-738.605	-2.0712	-4.9466	92.9637
IMG_4540	1208.709	105.620	-738.593	-1.4247	-3.9637	94.0258

Table 2. Exterior orientation parameters from Racurs Photomod

Image	**Xo (m)**	**Yo (m)**	**Zo (m)**	**ω (deg)**	**φ (deg)**	**κ (deg)**
IMG_4534	1202.535	105.460	-738.118	0.0076	-0.9871	92.1701
IMG_4535	1204.022	105.486	-738.277	-0.4395	0.4595	92.7761
IMG_4536	1205.930	105.559	-738.445	-1.5752	-0.6627	91.9303
IMG_4538	1207.642	105.623	-738.620	-2.1565	-4.7985	92.9204
IMG_4540	1208.729	105.631	-738.611	-1.5175	-3.8336	93.9803

Table 3. Exterior orientation parameters from Agisoft Metashape

4.3.2 Surface determination: The stage of surface determination, i.e., the detailed description of the surface of the object is very crucial for the correct production of the orthophotos. This procedure needs careful checking irrespective of the method used for the surface determination. In the case of the Racurs Photomod DPW, the software gives the unique opportunity to the user for stereoscopic restitution, i.e., to observe the points and lines collected along with the stereoscopic model. In this way, the correctness of the surface description is ensured almost 100%. The problems in this case appear in border line situations as may be apparent in Figure 4(b). In this case, the surface of the object is falsely, but intentionally, extended outside the object. This enables the correct production of the orthophoto up to the border. The extra part, outside the border, is easily deleted afterwards from the orthophoto. This procedure ensures full control over the projection of the texture on the surface and a correct orthophoto (Figure 5). For the topmost detail, i.e., the capital and the amphora on top, extra laborious stereoscopic restitution was necessary for the correct description of the complicated surfaceIn the case of the Agisoft Metashape processing, the software produced a dense point cloud, and a mesh, which needed some processing for removing unnecessary or erroneous points (Figure 6). It is apparent that at certain areas the automated procedure was unable to determine points on the object's surface, although there are no photometric artifacts on the images. These areas appear as white, i.e., without information, in Figure 6. However, the orthophoto produced (Figure 7) presents no gaps, due to the hole filling algorithm incorporated into the software. Obviously, the user has no control over the final automatically completed surface. Hence, the orthophoto might look complete, but could possibly contain geometric errors.

Both point clouds were compared within the CloudCompare® software. In Figure 8 this comparison is illustrated. It is apparent that almost all differences are well within the 2cm limit imposed by the final product scale (1:50).

Class	Value (m)	#distances	%
1	0.000-0.005	3703	62
2	0.005-0.010	1748	29
3	0.010-0.015	284	5
4	0.015-0.021	66	1
5	0.021-0.026	33	0.5
6	0.026-0.031	18	0.3
7	0.031-0.036	14	0.2
8	0.036-0.041	117	2
		5983	100

Table 5. Distribution of the point cloud differences

In Table 5 the distribution of the distances as determined by CloudCompare is illustrated. They range between 0 and 4cm with about 97% of the differences being under 2cm. This distribution is also illustrated in the histogram graph of Figure 9.

4.3.3 Orthophoto evaluation: The final orthophotos for each processing method were also compared both for their completeness and geometric accuracy. Both orthophotos were produced with a Ground Sampling Distance 9GSD) of 2mm, which is common practice for large scale products. In addition, they were projected on the same projection planes and in the same reference system, determined by the GCP's used.

Firstly, the geometric accuracy was evaluated by measuring the coordinates of the 4 pre-marked GCP's (Table 6) on the orthophoto and comparing them to their coordinates determined by the geodetic measurements and projected, of course, on the same projection planes. As may be seen in Table 6, these differences are within the range of 2-4 pixels, with the measurements on the Racurs Photomod orthophoto being overall slightly better. This may be due to the fact that only stereoscopically determined points and lines were employed for the description of the surface.

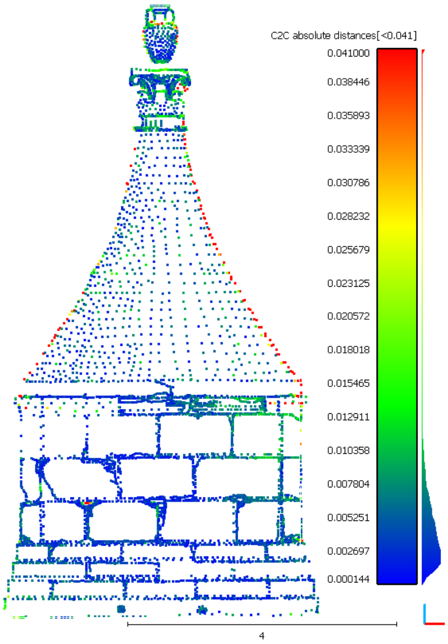

Figure 8. The results from the comparison of the Metashape point cloud with the stereoscopic restitution points in CloudCompare.

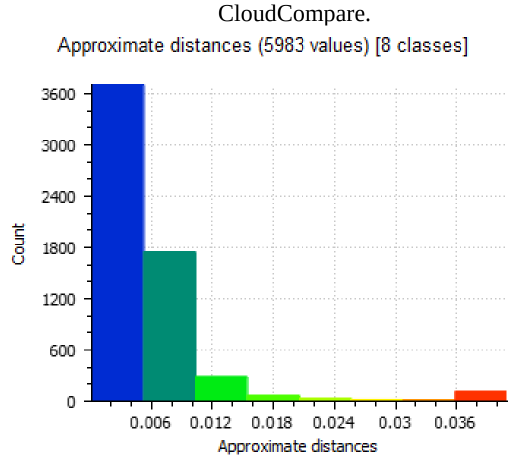

Figure 9. Distribution of point cloud differences

Ortho	Racurs Photomod			Agisoft Metashape		
GCP	dist	ΔX	ΔY	dist	ΔX	ΔY
1	0.005	-0.005	0.002	0.008	-0.006	0.005
2	0.004	-0.004	-0.002	0.008	-0.007	0.004
3	0.007	0.003	0.006	0.005	-0.001	0.005
4	0.006	0.006	0.000	0.006	0.000	0.006

Table 6. Distances (in m) of pre-marked targets on both orthophotos

Figure 10. The Racurs Photomod restitution superimposed on the Agisoft Metashape orthophoto

Subsequently, the two orthophotos were subtracted with an image processing software. The result is shown in Figure 9. It is apparent that there are large differences at the borders of the object, as expected. It was already pointed out that in these areas the description of the surface is problematic for both procedures. In the rest of the image of the differences, some lines appear on the masonry. These do not exceed in width 2-3 pixels, which is well within the already determined geometric accuracy.

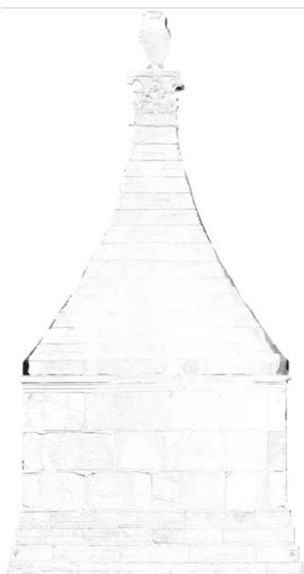

Figure 9. The result of the subtraction of the two orthophotos

In Figure 10, the stereoscopic restitution produced manually from the Racurs Photomod DPW is superimposed on the orthophoto produced from the Agisoft Metashape software. From this comparison it is apparent that the Agisoft Metashape orthophoto is not complete in several parts of the object, thus resulting in wrong shape. This is a serious defect of the automated procedure since there are very few ways to check and correct that. In addition, some more differences can be observed in the details, which is certain that they have been imaged, but not automatically determined. This case has been encountered many times in similar comparisons and is a major pitfall for the automated photogrammetric procedure.

The observed differences and gaps in the Agisoft Metashape orthophoto (Figure 10) could directly be attributed to the incomplete dense point cloud produced by the automated software (Figure 11), but also to the surface (Figure 6), which presents gaps in these particular areas. The incomplete parts are mostly at the base of the conical roof and at the edges of the structure. They may only be attributed to the matching algorithm, which, of course, is not revealed by the software manufacturers.

Figure 11. Dense point cloud from Agisoft Metashape

5. CONCLUDING REMARKS

In this effort we have attempted to compare and evaluate the procedures of conventional stereoscopic photogrammetry in a DPW and the contemporary automated photogrammetric and computer vision processes both for their operation and results. The comparisons were based on data collected for a student course and for the documentation of a cultural heritage monument. Cases like that are considered as demanding, as they deal with complex objects, large scale products and demand higher accuracies and increased resolutions.

All illustrations have been shown for the same façade of the K3 burial monument for which the same images and the same ground control points were used for obvious reasons of impartiality. An initial general statement from the evaluations is that automated methods can process more images, freely taken in space, while stereoscopic methods tend to process fewer images taken with stereoscopic vision in mind. The way images are taken is a constraint for both methods, but in opposite sense for each case.

In the case of the process on a Digital Photogrammetric Workstation (DPW), the Racurs Photomod v. 7, the following advantages have been established after the thorough practical comparisons. Firstly, the user has full control on the algorithmic processes of all steps, from inserting the images in the project, the orientations and adjustments, the determination of the surface description (DSM) and the production of the orthophoto. Moreover, accurate observations of the necessary points (GCP’s or tie points) are possible, while the addition of new points is a very easy procedure. Consequently, the adjustment results are the outcome of more accurate and controlled procedures. The orthophotos are equally, if not more, complete with the use of less images, which definitely is an asset. Finally, the stereoscopic observations allow for the determination of tie points in areas of the images where illumination is not favourable, e.g., shadows, and on textureless surfaces.

On the other hand, the procedure on a DPW is laborious and time consuming, requiring specialized expertise from the user, especially for the stereoscopic observations. Additional calculations for the separate coordinate systems are necessary, for the coordinates to comply with the aerial photogrammetry case. This results to the orthophotos being also in different coordinate systems, which, however, is common in 2D projections at large scales.

Figure 12. Final drawing with orthophoto of the Eastern façade

Automated software employing SfM/MVS procedures offers speed, which is an invaluable advantage. In addition, a huge number of tie points is determined, which contributes to the robust adjustment of the orientations. At the same time, a large number of images can be processed, a fact which may lead to larger and perhaps more reliable networks. Finally, this kind of software is extremely user friendly, which has led to the "democratization" of photogrammetric applications.

On the other hand, it is this user friendliness and automation that very often misleads the non-expert users to accepting all results and products without criticism. This leads to erroneous results, which do not serve the scope of geometric documentation. In addition, the users do not have control on the automated surface determination, as it depends on the quality of the images and the texture or the lack of it on the object. Hence, very often one is faced with incomplete surface areas, which cannot be filled with the available algorithms. Moreover, problems arise at the borders of the objects if they have not been photographed correctly. Finally, as the number of images increases, the computing power necessary to process them is geometrically increased.

There is no definite answer to the question of the title of this paper. There is no clear winner in the battle between conventional stereoscopic photogrammetry on a DPW and the automated SfM/MVS software. The choice of the user should be based on the availability of the software, the nature of the object and the expertise of the users.

Using a multitude of images from the DSLR and the UAV and with the help of the automated software, but with a lot of effort in processing the dense point cloud and mesh to end up with a correct surface of the object the drawing of Figure 12 was produced. It has all merits of both methods, as it has exploited the stereoscopic image pairs, the multitude of images taken from different viewing angles and the expertise for processing the surface in a suitable software.

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