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USE OF VARIOUS SURVEYING TECHNOLOGIES TO 3D DIGITAL MAPPING AND MODELLING OF CULTURAL HERITAGE STRUCTURES FOR MAINTENANCE AND RESTORATION PURPOSES: THE THOLOS IN DELPHI, GREECE

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ABSTRACT

This work was developed to train graduate students as part of the Delphi4Delphi project dealing with the digital reconstruction of the archaeological site of Delphi. In this part of the project, various technologies were used for 3-d digital mapping cultural heritage structures for maintenance and restoration purposes. The use of various surveying technologies such as UAS, Total station, digital camera, Lidar scanner and GPS to map in 3d the remaining of the monument Tholos and the surrounding area in Delphi Greece and based on such mapping to restore the entire structure is covered in detail. The remains of such monuments are a few columns standing up joined with original elements on top. In this part of the project GPS was used to establish the reference system, total station was used to measure a number of control points for UAS, close range photogrammetry and Lidar scanner, UAS was used to map precisely the surrounding area together with the structure, close range photogrammetry and Lidar scanner were used to map the vertical surfaces of the structure. Processing of above data from all surveying technologies created enough point cloud to map precisely the remains of the structure and expand their architectural design to precisely restore the entire Tholos monument. Also all digital data are used by software for the construction of 3D terrain and 3D models which when inserted into Game Engines software aim at the creation of educational scenarios.

KEYWORDS: surveying, photogrammetry, UAS, laser scanner, monument mapping, restoration, education, game engines

1. INTRODUCTION

Our era could be named as the cyber era or digital era. The New information and signal processing technologies alter our lives and the way in which we perceive it outwith the imaginable. This further ulterior over is the point in space-time in which coalition of science, technology and art openly combined for the 3rd Cultural Revolution, and for environmentally sustainable abundance. However, this time, the "Outwith" not only explores the dynamic 3D screen, it moves on from the bits to the atoms and incorporates 3D-printing and digital cloud-distribution, which combined to relevant scanning or photographic technologies create a virtual reconstruction environment as a real world. We are entering the central source for current and emerging trends in cultural heritage informatics with new disciplines, sub-disciplines and terminology to emerge. Virtual, cyber-archaeology (Forte, 2005) and cultural heritage to cyber-archaeometry, (Liritzis et al, 2015) are matters that are tackled. The restoration, reconstruction and virtual archaeology case studies, over the World, as a result of advanced technology emerging from computer sciences, however, stress the naturalistic methodology, challenges digital reconstructions and serious games. There may provoke also harassment and emergence of fundamental hermeneutical questions which serve as the basis of a synoptic and synthetic philosophy that combines art and science corresponding to classical techne, logos and ethos. In 1999, about nine years after the invention and public domain of the World Wide Web project Tom Levy and his team made a commitment to "go digital" by recording all field measurements on excavations in Jordan related to the role of ancient metallurgy on social evolution. That was the start of a growing field of 3D visualization. This first application was referred to as on-site digital archaeology (OSDA) 1.0 (Levy et al., 2001) with a summary of the most important new developments in OSDA 3.0 (Levy et al., 2010) that make it a much more versatile system. In our present work the OSDA takes the form of Fig. 1 for restoration and maintenance and takes advantage of both off-the-shelf technologies and also includes new computer programs and hardware developed specifically to solve archaeological/cultural heritage problems that face researchers working around the world today. The Digital archaeology appears together with The Project that was the first public available information website to connect and share documents on personal computers via the internet (published by Tim Berners-Lee at CERN in 1991 who used HTML 1.0. Its first web address was http://info.cern.ch/hypertext/WWW/TheProject.html, which described the World Wide Web project). The web turns 24 this year, and while national libraries, archives, universities, and other cultural heritage institutions have been archiving the web since the late 1990s, the early web, the first website from World Wide Web co-inventor Sir Tim Berners-Lee, created in 1991. The website featured at Digital Archaeology is believed to be the earliest available copy, from 1992. (Liritzis et al., 2015).

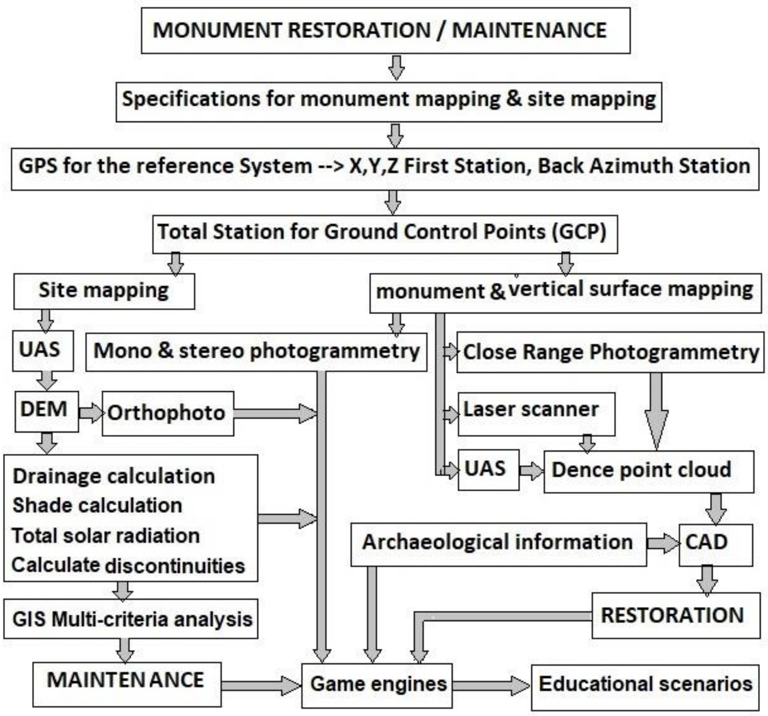


Figure 1. Diagram for restoration and maintenance.

The CD-ROM of course use of digital record in arts and humanities has been initiated earlier (e.g. the Perseus Project, Perseus Digital Library planed by 1995 at Tufts and issued in 1992 by Yale University Press, TLG). More digital publications in CD or online have been developed since then, that have contributed a great deal in the investigations of humanities, the cultural heritage being a major issue (Sabharwal, 2015).

In the present article we focus on a case study or a tutorial training that combines new digital technologies, methods and instrumentation, focused on the well-known Tholos monument in Delphi Greece that provides an example of Hi-Tech friendly used and taught to the apprentice on a Masters level and unfolds the rationale of potential relevant studies of tangible cultural heritage.

This described interdisciplinary work to train graduate students as part of an ongoing large enterprise Project (Delphi4Delphi) deals with the digital reconstruction of the archaeological site of Delphi. The technologies were used for 3D digital mapping, use of various surveying technologies such as Unmanned Aerial Survey (UAS) (Stefanakis et al., 2013), Total station, digital camera, Lidar scanner and GPS (Hatzopoulos, 2008) for the monument and the contextual area. UAS was used on a supplementary GPS and a photogrammetric survey and interconnected manner with close range photogrammetry and Lidar scanner, while processing of all data created enough point cloud to map precisely the remains of the structure and expand their architectural design to precisely restore the entire Tholos monument (http://www.danielgm.net/cc/), (Autodesk - AutoCAD 2015), (Altuntas et al 2017; Salama et al., 2017).

1.1. Tholos history

Within the sacred archaeological site of Delphi is the sanctuary of Athena Pronaia or Marmaria (see below Figs.6, 11 etc), which is located to the southeast of the sanctuary of Apollo (Pedley 2005,151), and its importance relates to those appealing to Apollo via priestess Pythia for an oracle (Luyster, 1965, 148, Liritzis and Castro, 2013). The narrow long level paved area includes altars, temples, treasuries and the tholos. The Archaic temple of Athena contains several altars, the oldest dates to the 7th century B.C.E. The tholos structure was constructed sometime between 400-375 BCE by architect, Theodorus from Phokaia in Asia (Lawrence 1957, 184), has a circular base of 13.50m in diameter, encircled by twenty Doric columns on the outer circle and ten Corinthian columns on the inner circle (Valavanis 2004, 232). The doorway to the cella is a triple opening formed by two Ionic half columns which are engaged directly on top of piers and set between posts or pillars called *antae*. The building was decorated with moldings and relief metopes in the diorama of the peristyle and wall. The function of the tholos is not completely clear with some prevailed theories (Valavanis 2004, 232; Marmaria 1997; Michaud 1973; Lawrence 1957, 184). All three ancient Greek architectural orders were involved in this construction. In 373 BC a major earthquake caused stones from the Phaidriades rocks to fall, destroying the temples and reconstruction began in 370 BC but ceased after a series of sacred wars. The tholos structure has been partially reconstructed; three columns have been restored along with partial cornices, pieces of the guttering, metopes, and triglyphs. Featured on the exterior friezes were images of the battle between the Amazons and the Centaurs. The gutter of the exterior Doric entablature was ornamented with lion head spouts. The blocks of the tholos are joined together carefully, and the joints coincide with the central points of the triglyphs and metopes. The blocks were stippled except for polished bands at the margins. Also done in the Athenian Propylaea, this method emphasizes the joints more than other smooth marble architecture of Athens.

1.2. Project design

Design specifications (Hatzopoulos et all, 2006) are analyzed as follows:

The reference system for this project is to be the EGSA-87 Greek reference system (EPSG:2100 - GGRS87 / Greek Grid). Such reference system is to be established by GPS with an accuracy compatible to Google map.

Topographic mapping of the wider area is to have a horizontal and vertical accuracy of ±5 cm. The final product will be an orthophoto as a horizontal map with corresponding digital elevation model -DEM. Topographic mapping will be performed by UAS technology.

Close range photogrammetry and laser scanner will be used to survey the vertical surfaces of the Tholos structure. In addition, close range photogrammetry will be used for a vertical wall to map the building blocks of stones. The accuracy expected from close range photogrammetry and laser scanner is ±1 cm.

Control points for UAS, close range photogrammetry and laser scanner will be surveyed by total station with an accuracy of ±5 mm. Restoration model of tholos will have a horizontal accuracy of ±1.0 cm and a vertical accuracy of ±1.0 cm. Gaming data will use the orthophoto and DEM of accuracy ±5cm as it will be produced by UAS technology, and the restoration model.

2. REFERENCE SYSTEM AND TOTAL STATION SURVEYS

The reference system was created by using two points A and B measured by a hand held GPS. Point A was used as the first station to be occupied by the total station, while point B was used to compute a backsight azimuth. The measured quantities for point A and B are given in Table 1 and the last row in the Table 1 shows the computed azimuth and distance. The azimuth and the distance was computed by an in house developed educational software (Hatzopoulos, 2008) as shown in Fig. 2.

Table 1. Measured and computed quantities

No.	X	Y	Z
A	369730	4259870	484
B	369650	4259876	482
Az	304.7657	Distance	80.225

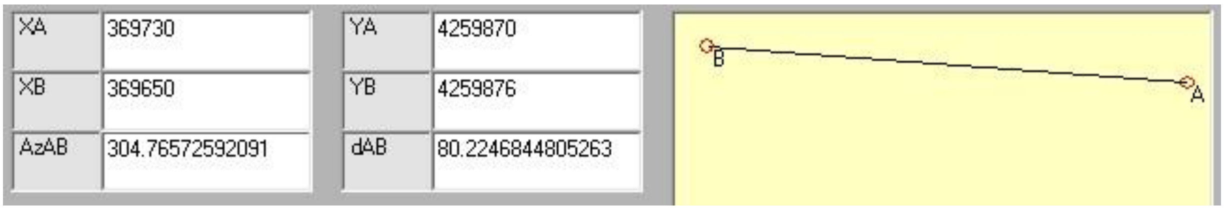


Figure 2. The output of the computation of azimuth and distance.

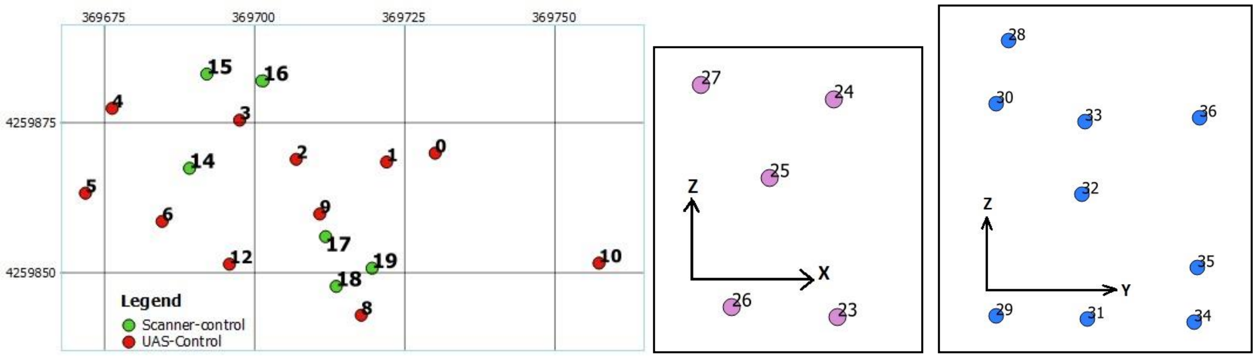
The GPS receiver was adjusted to the EGSA-87 Greek reference system (EPSG:2100 - GGRS87 / Greek Grid) and the accuracy of the hand held GPS was sufficient for compatibility to the Google map in this project.

Consequently, the total station was used to measure a number of control points for UAS, Laser Scanner and close range photogrammetry as shown in Table 2.

Table 2. List of the measured control points by total station

UAS Control Points				*Scanner Control Points*				*Photogrammetry Control Points*			
P	**X**	**Y**	**Z**	**P**	**X**	**Y**	**Z**	**P**	**X**	**Y**	**Z**
0	369730.000	4259870.000	484.000	14	369689.231	4259867.476	483.448	23	369701.690	4259878.672	483.428
1	369721.904	4259868.521	483.545	15	369692.112	4259883.194	488.780	24	369701.645	4259878.650	484.756
2	369706.827	4259868.982	483.558	16	369701.292	4259882.061	489.956	25	369703.728	4259878.260	484.276
3	369697.587	4259875.502	483.315	17	369711.733	4259856.077	482.831	26	369705.281	4259878.029	483.488
4	369676.330	4259877.470	483.380	18	369713.503	4259847.780	482.367	27	369705.247	4259877.842	484.842
5	369671.880	4259863.326	482.603	19	369719.481	4259850.811	483.505	28	369705.404	4259857.635	489.002
6	369684.661	4259858.626	483.565					29	369705.362	4259857.423	484.338
8	369717.667	4259842.973	482.223					30	369705.324	4259857.430	487.937
9	369710.760	4259859.858	483.056					31	369706.466	4259858.980	484.285
10	369757.318	4259851.656	483.281					32	369706.395	4259858.882	486.398
12	369695.888	4259851.478	482.189					33	369706.392	4259858.937	487.636
22	369710.752	4259859.873	482.081					34	369706.990	4259860.789	484.234
								35	369706.979	4259860.844	485.157
								36	369706.949	4259860.880	487.703

The accuracy of theodolite measurements was tested on check points and it was estimated ±5mm.



(a) for UAS/scanner *(b) on the wall* *(c) on the columns*

Figure 3. Location of control points

The location of the control points is shown in Figure 3, (a) within the wider area for the UAS and the scanner, (b) on the wall for close range photogrammetry and (c) on the columns for also close range photogrammetry.

All field surveys were performed between 9:00 am and 1:30 pm. During the survey time the 36 students who were attending the field performance were subdivided into three groups to be able to attend all survey sections and participate in the operations with the instruments starting with close range photogrammetry and rotating to laser scanner and total station. The operation of the UAS was attended by all students.

3. CLOSE RANGE PHOTOGRAMMETRY SURVEYS

Although nowadays Photogrammetry has been automated with the help of computer vision algorithms, there is still need for young emerging professionals to get acquainted with "traditional" photogrammetric practice in order to understand the pitfalls usually appearing when applying the automated processes.

Hence the 36 students were exposed to both stereoscopic and single image Photogrammetry. The main problem of extracting 3D metric information from 2D images is that the third dimension is hidden in the form of perspective distortions. Hence for extracting it we need at least a second image, just like our eyes and brain do to perceive depth. However, when there is not third dimension in the object, i.e. when it is planar, this extraction may be performed with a single image. Both these photogrammetric processes were implemented during the workshop in Delphi.

For the stereoscopic photography the student were asked to plan the image sequence according to the lenses available for the particular camera. Then a rough photography plan was devised, so as to ensure: (1) at least 70% overlap, (2) almost parallel camera axes, (3) almost the same image scale, i.e. by keeping the same distance from the object, and, (4) ensuring similar illumination conditions in all images. A sample stereopair is shown in Fig. 4.

Figure 4. A sample stereopair of the Tholos

For the orientations and especially for georeferencing and scaling the stereoscopic model, ground control points in the form of targets were put on the object. The minimum required number is 3, but 7-8 were measured, including some detail points higher up the monument (see, Table 2). These GCP's were measured geodetically and their coordinates were later used for absolutely orienting the stereoscopic model.

For that purpose, the Digital Photogrammetric Workstation PhotoMod by Racurs (www.racurs.ru) was used, as it is offered as a lite/trial edition with some limitations by the manufacturers. The students were able to observe the stereo pair stereoscopically and became familiar with conventional photogrammetric restitution. As this is a highly time-consuming process, the restitution was not finalized in Delphi.

On the other hand, single image Photogrammetry was also demonstrated using as object a vertical supporting wall, close to the Tholos. The process of producing an orthogonal projection of an image of a planar object is called image rectification and it actually is a projective transformation of the original image. For calculating the 8 parameters of this transformation, at least four points are needed on the planar object. Usually more points are used in order to ensure the desired accuracy. In this case five points were used and can be seen in Figs. 5a and 5b.

For the digital rectification the freeware software RDF of the University of Venice was employed. It is very simple in operation and the rectification was performed successfully (Fig. 5a). For demonstration and educational purposes additional images were taken with high axis inclination (Fig. 5b). These were also rectified by the same software, with some blurring effects in the parts where the original image scale is very small, very small, i.e. the part of the object far from the camera.

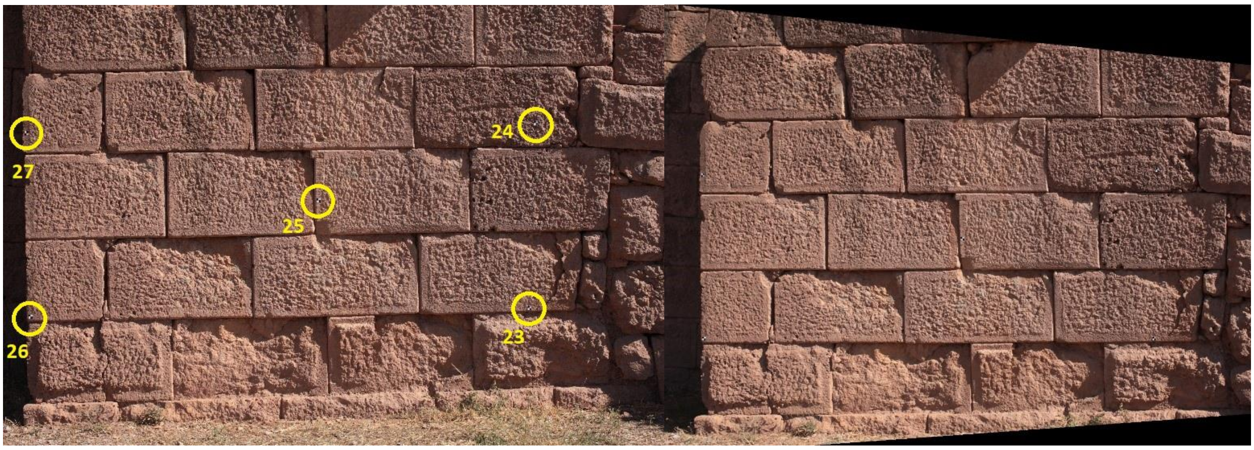


Figure 5a. The original image to be rectified with the five targets on the wall (left). The rectified image (right.

Figure 5b. A second oblique image for the same object rectification

Figure 6. A panoramic image of the site. For that purpose the RICOH Theta S 360 deg camera was used.

A modern tendency nowadays is to investigate the possibilities of metrically exploiting panoramic images (Fig. 6). As demonstration such panoramic images were also taken in situ, without performing any processing. For that purpose the RICOH Theta S 360 deg camera was used.

4. LASER SCANNER MEASUREMENTS

Laser scanner measurements were applied for the production of the 3d surface of Tholos. The equipment used was a Time-Of-Flight (pulsed) terrestrial laser scanner, the Leica Scanstation 2 (Figure 7). This scanning system is suited for ranges of up to 300m and has a maximum field of view of 360° in the horizontal plane and 270° in the vertical plane. Leica ScanStation 2 is equipped with a dual-axis compensator and an integrated digital camera for colored scans, it captures up to 50,000 points per second and can be used for indoor or outdoor scanning in all light conditions. The Time-Of-Flight principle is the most popular scanning system with accuracy within a few millimeters to centimeters depending on the extent of maximum range.

Figure 7. The Leica Scanstation2 laser scanner

Figure 8. The 3"x3" square tilt & turn HDS target on a tripod with plummet tribrach

The scanner positions were determined carefully having in mind the following rules (Lerma García et al., 2008):

1. The positions provide large area coverage without having obstructions in the line of sight and that produce the least shadows.
2. The minimum/maximum range limits of the scanner were fulfilled to reach certain accuracy, the larger the distance to the object, the lower the accuracy and resolution.
3. Minimize the appearance of low intersection angles
4. Visibility of artificial targets

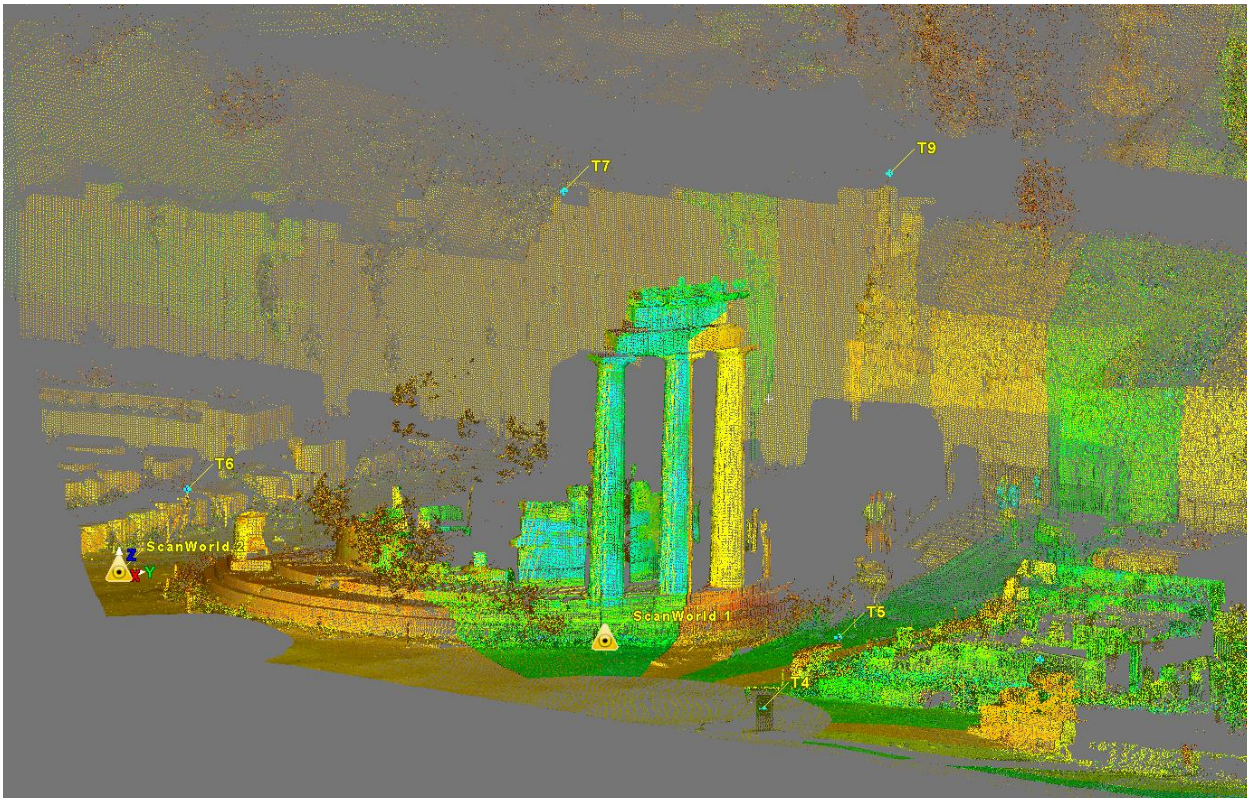


Figure 9. The Point Clouds after registration

The resolution of each point cloud was 0.005 m, in order to represent all the details of the object.

Special reflective targets (3″x3″ square tilt & turn targets) were placed before scanning in such a way that at least four of them to be visible from each scanner position. The targets were measured with the total station and the 3D coordinates (X, Y, Z) were calculated for the geo-referencing of scans to the reference system and the accurate registration of multiple scans to each other with the target-to-target registration method. The targets were placed, using tripods and plummet tribraches (Fig.8), around Tholos and not on it because it was not allowed. Their position was carefully selected so that they didn't obscure important details of the subject. Part of the final point clouds after the registration is shown in Figure **9**.

5. UAS SURVEYS

Unmanned Aerial System based photogrammetry have a multiple role in the reconstruction and educational process (Stefanakis et al, 2013):

- provide a wider area digital base-map/orthophoto for various related tasks
- Obtain a high detailed Digital Surface Model (DSM), to be used for terrain analysis, survey measurements or photorealistic modelling background.
- Provide significant detailed 3D Point cloud for the study area and especially for regions that are difficult or unattainable with laser scanning
- Capture scenery and artifact texture in desired detail, to provide color information for laser scanning or unattainable places with close range photogrammetry.
- Immerse Students to modern technologies and methods, emphasizing bottom-up approach in Concept of operations

5.1 Concept of Operations (CONOPS)

UAS Survey starts with the Concept of operations procedure (Pratt et al., 2009), in which students decided the desired spatial resolution, radiometric capabilities and spectrum of captured data (see Figure 10). Consequently, they incorporated into the process the mentioned in Sections 1.2 and 2, affecting the specifications of sensor type, weight and attributes.

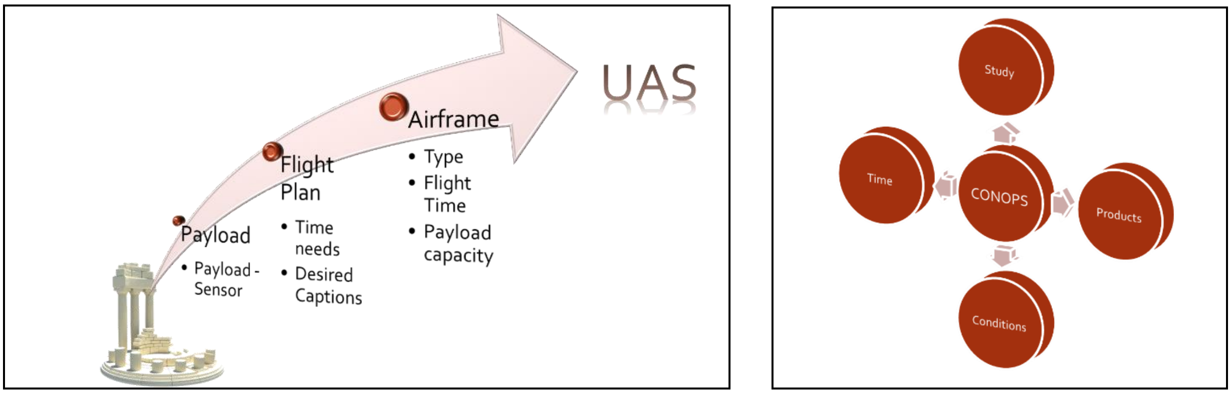


Figure 10. Concept of Operations (CONOPS)

Combining the study area requirements like scale, constrains and restrictions with the above-mentioned sensor, students concluded to the most appropriate unmanned aerial platform (Valavanis et al., 2014a) needed to carry the sensor and perform the acquisition flights.

5.2 Flight Planning & Mission execution

5.1.1 Flight Planning

Flight Planning procedures, validate CONOPS outcomes and helps to delve into the Study area and environment requirements. In essence, instead of calculating & setting parameters for each subsystem, students used a UAS Specific Software to obtain every single aspect of captured data, as we can see in the following picture from an open source UAS Ground Station software (mission planner, http://planner.ardupilot.com).

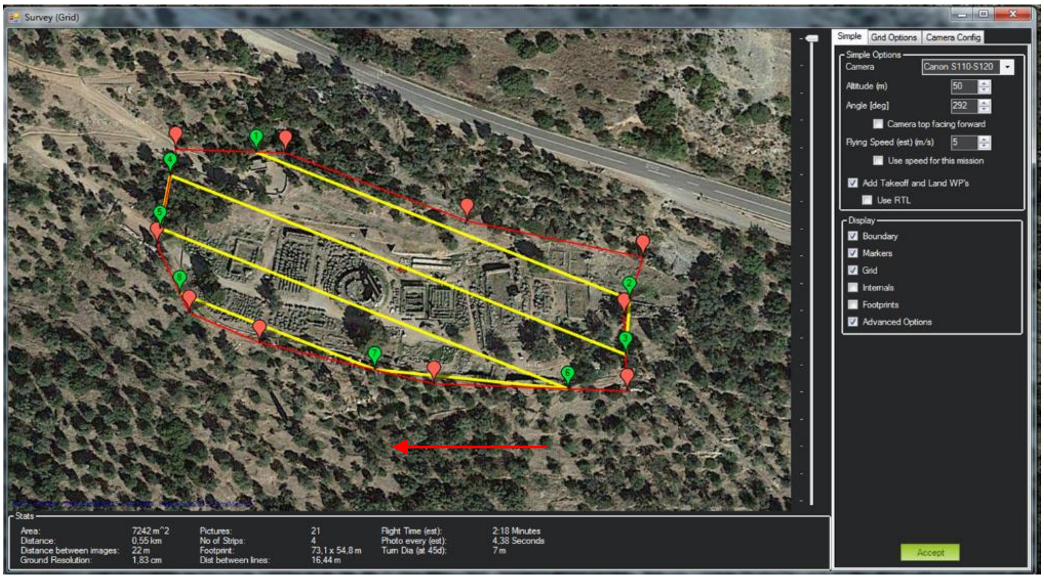


Figure 11. Ground Control Station (GCS) Software Automated Aerial survey menu, red bullets and red lines indicate the extend of the area to be covered, yellow lines are the flight lines and green bullets are the turning points of UAS.

In the survey menu (see Fig. 11), of most ground control station (GCS) Software, students can easily and efficiently calculate -given the parameters of the chosen sensor UAV physical properties, capture requirements and limitations- every flight path command to be executed by the UAS and expected deliverable, such us but not limited to:

- Ground Sample Distance
- Number of Captions
- Flight time
- Covered area
- Camera Trigger commands and Geolocation storing method
- Flight Speed and minimum Shutter Speed
- Sidelap and overlap
- The final UAS and deliverable Specifications were calculated as shown in Table 3 below:

Table 3. UAS and deliverable Specifications

UAS Specific	
UAS Airframe Type	Multicopter / octa-copter
Avionics - Autopilot	Opensource Hardware Software PIXHAWK 2.1
GPS Type	Dual Ublox NEO-M8P High Precision GNSS Modules
Payload Capacity	2 kg
Flight Time @ maximum payload and Cruise speed	19 minutes
Cruise Speed	5 m/s
Max Speed	16 m/s
Ground Station and UAS Category	A2, Line of Sight (LOS) With waypoint control
Radio Communications	Amateur License 433 band radio telemetry, 2.4GHz Control
Payload Sensor	
Sensor Type	42MP Full-Frame Exmor R BSI CMOS RGB
Image Width/Height [Pixels]	7952 x 5304
Sensor Width/Height [mm]	35.814 x 23.876
Lens Focal Length	28 mm
Flight Plan and Derivatives	
Flight Time	5 minutes (2'30'' excluding Take-off & Landing)
Area	8000 m^2
Sidelap/Overlap	75%
Number of Captions	52
Min. Shutter speed	1/1249
Flight Altitude	50m
Ground Sample Distance	0,8cm
Triggering and Geotagging method	Sony-Multi port USB Trigger event via PWM and logging
Attribute logging	Active IMU and GPS logging (400Hz, 10Hz respectively)

5.2.2 Mission execution

Following CONOPS and Flight planning that took place in the previous class, students had to execute the automated mission at optimal conditions, combining a series of check lists arising from Remote Sensing Sciences (Mozas-Calvache, et al., 2012), Legislation and Operation manual/Risk assessment that briefly included:

- UAS Operation Manual Check list
- Optimal Weather Conditions
- Optimal Solar radiation and Shadows
- Hellenic Civil Aviation Authority Flight-plan Submission/Approval
- ICAO and Hellenic specific legislation guidance's regarding Drone Operations
- Local Antiquity's authorities guidance and permissions

Ground Station Software (http://planner.ardupilot.com) and Mobile internet made possible to comply with the above-mentioned procedures at real time, combining direct communication between the UAV and Ground station, while connected to the online system of the corresponding authorities (Puttock et al., 2015) as shown in Figs. 12 and 13 below.

Figure 12. Mission planer Provides information regarding the UAS Status and gathers flight data from ADS-B Equipped aircraft in the area

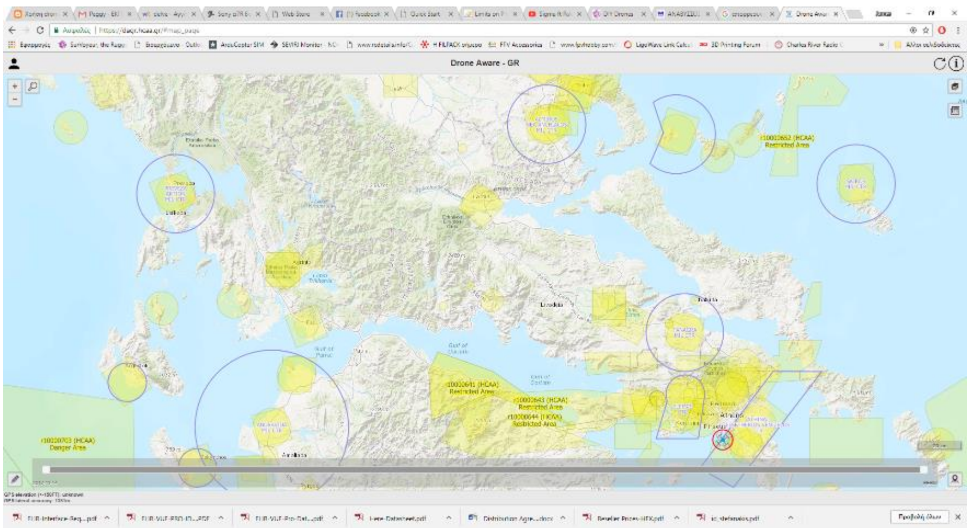


Figure 13. Drone Aware HCAA Online System was responsible to provide the necessary information regarding permissions and restrictions as well as weather data and mission approval(https://dagr.hcaa.gr/)

5.2 *UAS Data Processing*

UAS Data processing includes the raw captured data manipulation, log analysis, aero-triangulation and geo-referencing, as well as providing the first basic derivatives.

5.2.1 Image Geotagging and attribute matching

Most UAS based photogrammetry software, differ dramatically with their traditional ancestors and close range photogrammetry siblings, mostly because of the vast number of collected data and therefore the multiple aero-triangulated key/tie points. For that reason, aiding the computational routines providing information about pair selection it is considered mandate, especially in demanding projects (Valerio Baiocchi et al., 2013).

For that purposes students used the logging capabilities of the Avionics equipment along with GCS Software to match the appropriate information needed along with the Exchangeable image file format data (Exif), such as:

- Position (x, y, z)
- Exterior orientation (omega, phi, kappa), (Hatzopoulos, 2008)
- Sensor type and size
- Lens information

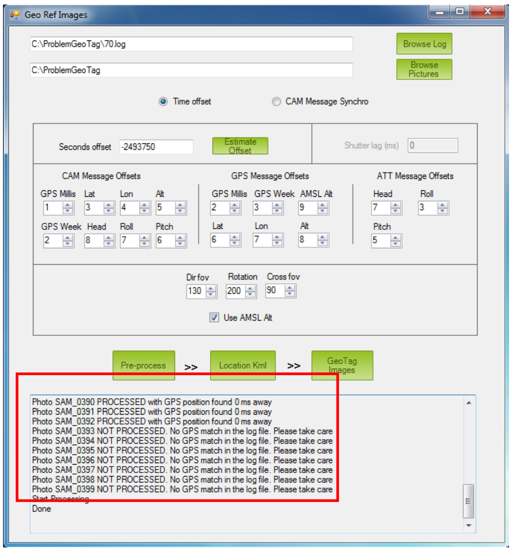


Figure 14. Resulted geo-tagged images and position error estimates.

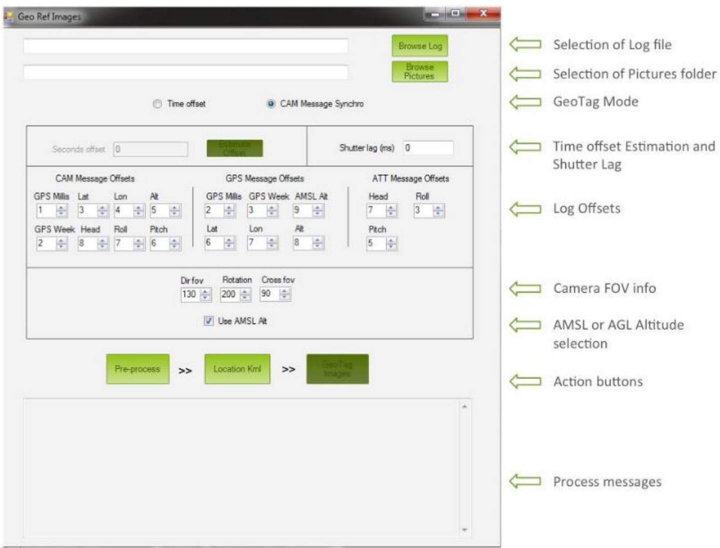


Figure 15. Mission Planner Geotagging tool interface

GCS Software takes into consideration the abundant Inertial Measurement Unit information to spatially interpolate GPS discrepancies to enhance accuracies, in an otherwise time-consuming process.

5.2.2 Aerotriangulation

For the aerotriangulation process we incited students to use modern UAS oriented software emphasizing the rapid growth of open source, while been able to balance between their current individual workflow and interoperability. Agisoft Photoscan Professional licenses were donated to the Post Graduate Program and it was used for data processing.

Students inserted to the photogrammetry software the acquired images, all information mentioned at 5.3.1 and ground control points (GCP's) measured with the total station, as shown in the following Figs. 16 and 17 (Chiabrando et al., 2011).

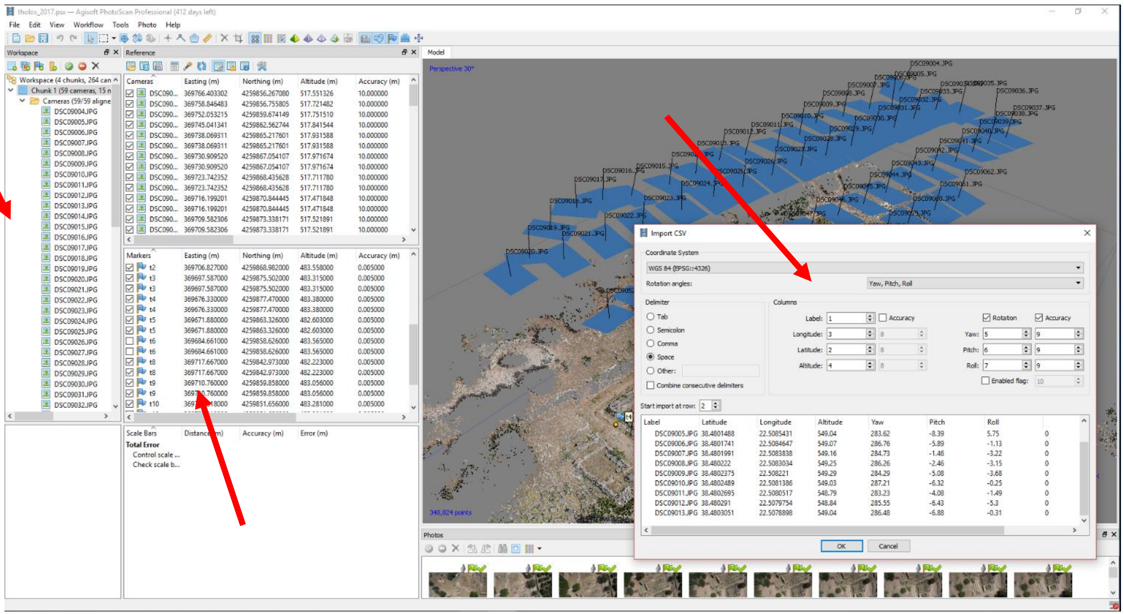


Figure 16. Loading Images, GCP's and image position/orientation to photogrammetry software. Note the difference of reference system between GCP and Images

Figure 17. Control point (GCP) and its target.

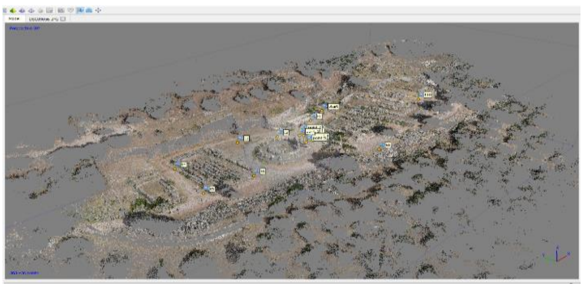


Figure 18. Sparse Point cloud generation and GCP'S (303.436 Points).

Figure 19. Dense Cloud Generation (5.417.319 Points)

Every GCP, was carefully chosen upon every image. The process was enhanced by the estimated positions and made easier to select and group images by GCP, even without the alignment process.

The next step, was to *align* images and generate the *dense* point cloud. Every photogrammetric software, offers unique enhancements and refining tools to optimize these two processes. Furthermore, each software vendor differently approaches the allocation and usage of computational resources, like multi-core threating, CUDA or other GPU based processing, cluster architecture support etc. Whatsoever, all of them share the same core of equations needed to complete the above-mentioned tasks, so we will not go in a further depth.

Following the mandate aerotriangulation processes, we moved on to the first derivative creation such us Digital Elevation Model (DEM) and Orthomosaic. DEM creation uses as input the Dense Cloud points (see Figs. 18 and 19), but the Dense cloud contains information from both Terrain, building and vegetation. In the case of Tholos we needed to calculate two different DEM files, one including Vegetation for shadow, wind, micro-climate analysis and one that is based upon terrain points for further exploitation like drainage analysis, slope, contour maps etc.

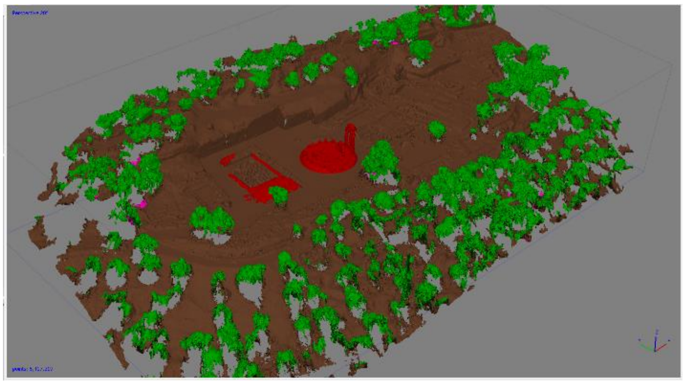


Figure 20. Classified Dense Cloud to: Ground, Vegetation and Structures

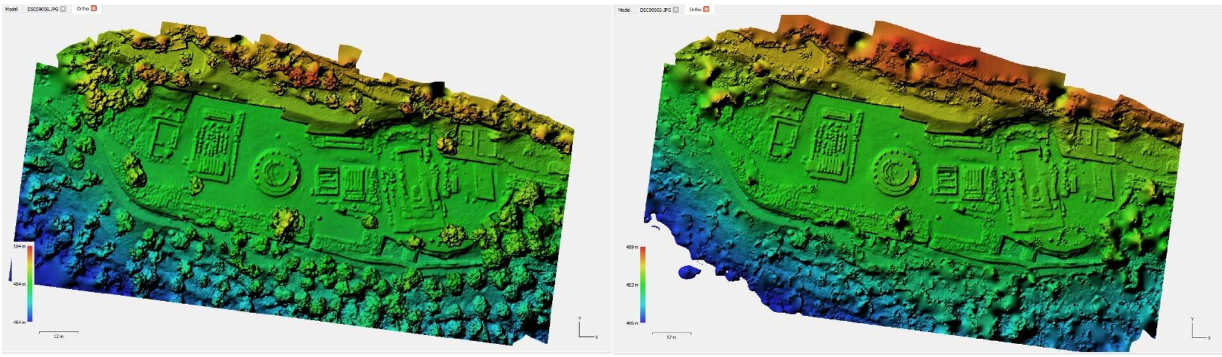


Figure 21. DEM Variants, with and without vegetation, respectively

Using Dense Point Cloud manipulation and classification tools, we were adept to classify the dense point cloud to every desired class (see Figs. 20 and 21), enabling export of desired variants (Jensen & Mathews, 2016).

Consequently, we proceed to the first final of derivatives, which is the orthomosaic as shown in Fig. 22. For this process photogrammetry tools take into consideration the primary images and DEM, to apply the geometrical transformations and image assignments (Matthias Lang et al. 2015). In this process, image assignment is done using the image with less distortion, along with proximity. In every case user must take into account the image quality and unwanted moving objects in the scene, choosing for a manual assignment at his judgment as shown in Fig. 23.

Figure22. Study area orthomosaic and seamlines of assigned imagery

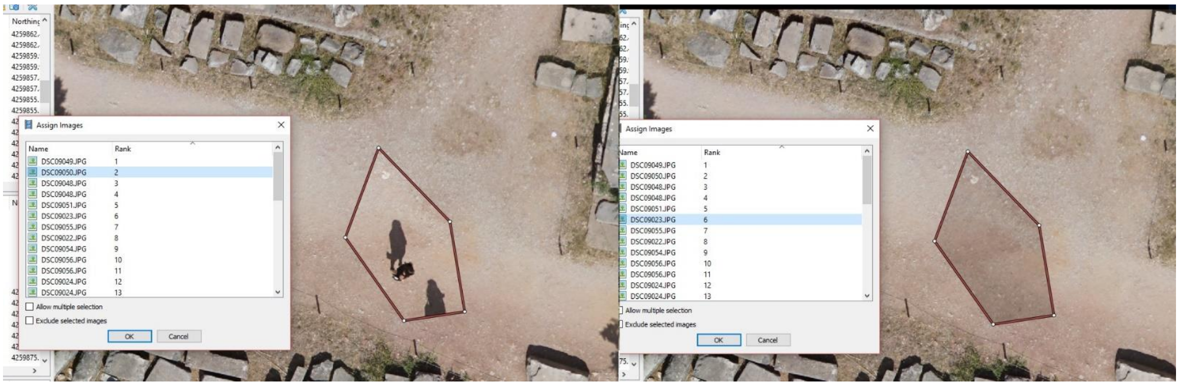


Figure 23. Manual image assignment to the orthomosaic process, to remove unwanted moving figures

As mentioned in previous chapters, every software vendor uses a variety of enhancing technics and automation tools. Though, all of them are subject to the same geometry principles and thus not mentioned in detail.

Finalizing the UAS Survey processes to disseminate as much as possible useful outcomes to the rest of the working group, a series of derivative products had to be exported. These derivatives included mesh and dense point cloud in various formats and versions, to maintain multi-disciplinarily and interoperability within the working group such as:

- Mesh files, with and without texture
- Mesh files, including or excluding vegetation and structures
- Dense Point Cloud in various formats (LAS, PLY, TXT), with point normals and colors
- Several aiding materials (3D Google earth, 3D PDF etc.)

6. RESTORATION/MAINTENANCE PROCESS

The approach this chapter regarding the restoration-protection of the monument will be as follows:

Use UAS Derivatives to:

- Merge data and other information for restoration
- calculate drainage and recommend appropriate actions
- calculate Solar Radiation, sunlight and shadow casting to improve/optimize siting, like visitor signage, security posts etc.
- mention, that in the unlike event of natural/human disaster, a detailed 3D survey could act as reference for restorations
- Study micro climate conditions in conjunction with Landscape architecture, in order to provide better visibility to visitors and at the same time keep constant wind levels within the monument site.

6.1 *Merge Data-Information*

In order to fill areas with less information, point clouds taken from different source (vantage points), must be aligned. In Cloud Compare Software (http://www.danielgm.net/cc/), which is an open source software for point cloud manipulation, we aligned the two point clouds the one from laser scanner as shown in Figure 9 and the other one from UAS using common tie points. It must be noted that this combination was necessary because UAS was programmed to take vertical photography, which does not cover completely vertical surfaces, while the laser scanner was scanning accurately the vertical surfaces. The combination of these clouds is shown in Figs. 24 and 25.

6.2 *Restoration from geometry aspect*

Scholars, quickly identified, that each one of the preserved columns was incomplete, either because of fractions or attempted restorations on their surface, either because of lack of data. In order to generate a column as complete as possible, we combined point cloud information from each source, by merging the point clouds in one set.

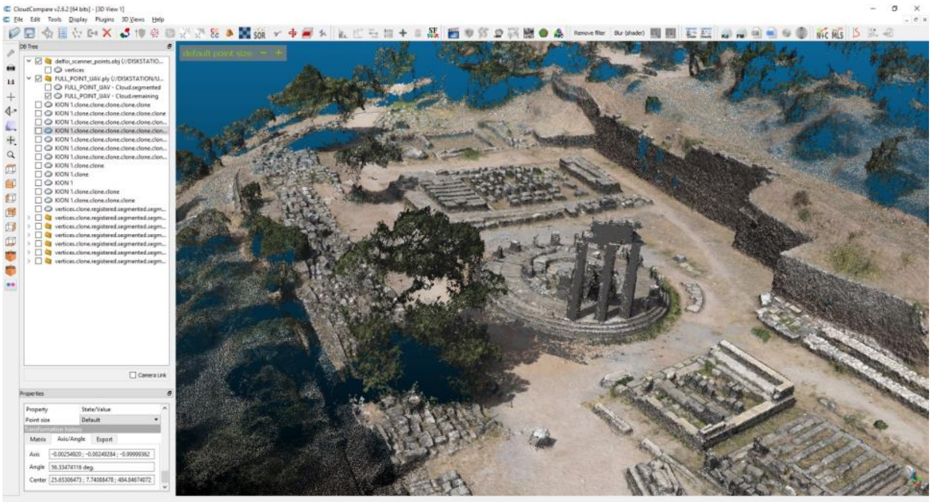


Figure 24. Importing Point Clouds from UAV and Lidar Scanner into Cloud Compare Software and doing the alignment by using Control points

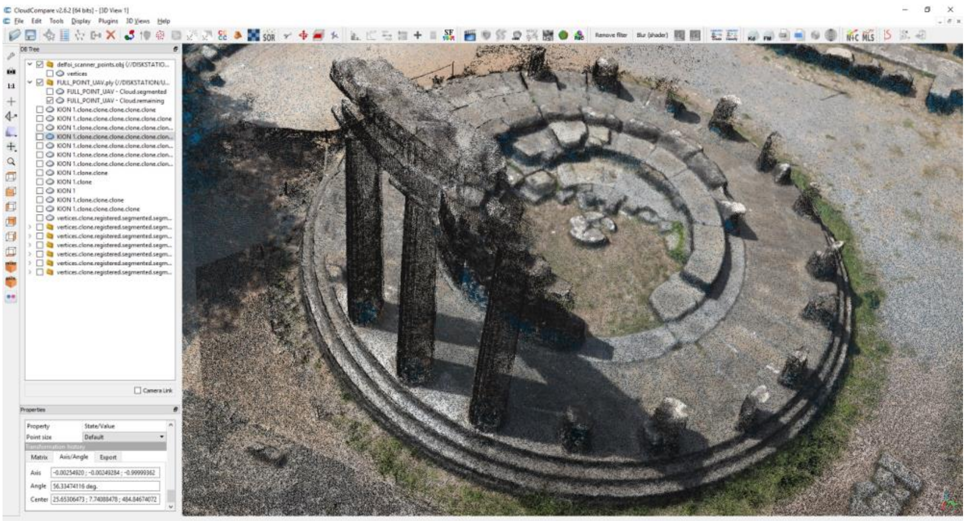


Figure 25. We can easily identify the enrichment of information, especially in airborne hidden areas.

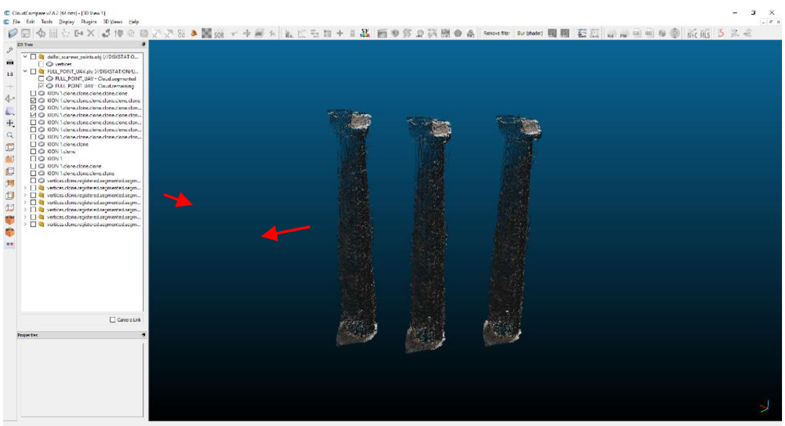


Figure 26. Abstracted columns to be aligned

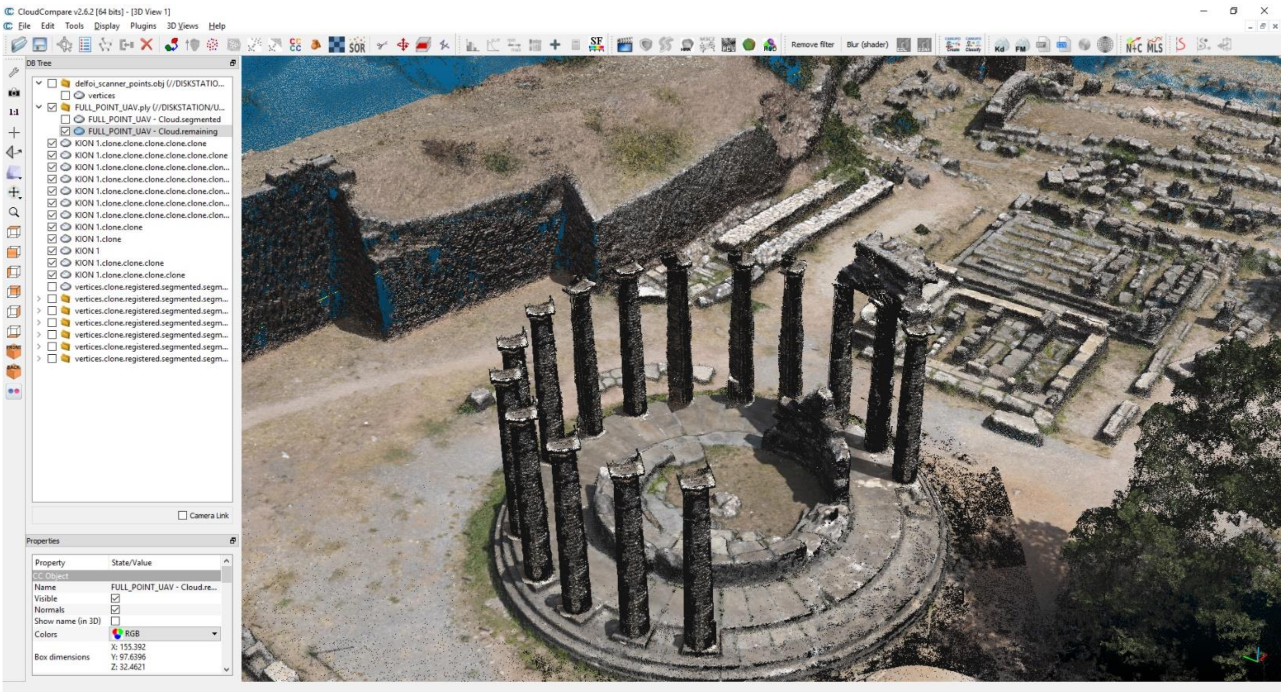


Figure 27. Column restoration process

The resulted column gained information from each assessed angle, provide us with a more accurate column model to continue with the restoration as shown in Fig. 26. The remains of the rest columns, as well as the columns capital orientation, helped us to establish the final placement as shown in Fig. 27.

Restoring the pediment is labor intensive procedure, because it involves non-reiterative objects like the relief sculpture. In order to study the edifice, we recreated the pediment, disregarding the relief sculptures by repeating the above-mentioned process (see Fig. 28).

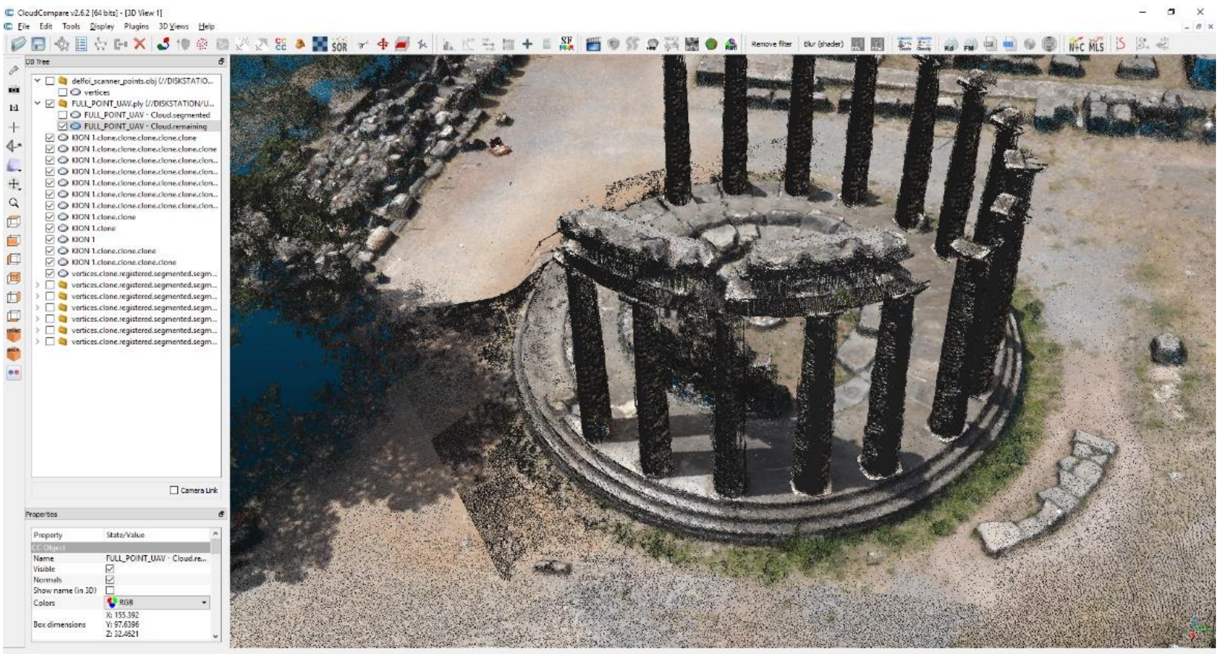


Figure 28. Pediment reconstruction

In order to correctly place the replicated pediment parts and identify the missing ones, students used CAD Software to extract the pediments section and revolve them along the monuments radius. This procedure involved three steps as shown in the Figs. 29 and 30 below. The exact use of the detailed plan of Tholos is not known and only suggestive alternatives at the moment have been presented (https://www.coastal.edu/intranet/ashes2art/delphi2/marmaria/tholos_temple.html).

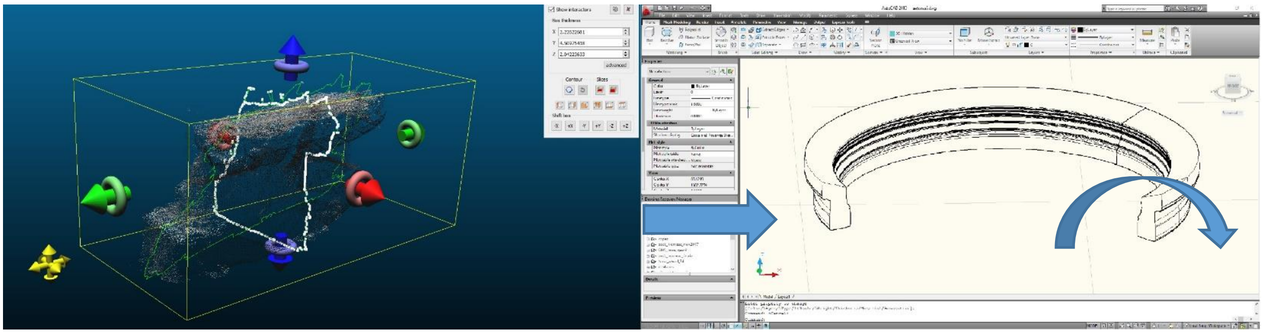


Figure 29. Export cross-section to CAD(eg DXF). Identify Radius and Arc. Revolve Cross Section (Autodesk - AutoCAD 2015)

Figure 30. Finalized Columns and Pediment Structures

6.3 *Protection and maintenance processes*

Several, worth mentioning technics regarding protection were showcased in class such us:

6.3.1 Drainage calculation

One of the most common work in the annual maintenance schedule of an archaeological site, is to ensure proper drainage, rendering the site accessible to public, while protecting the monument. Usually these practices are carried out using empirical observations, or measuring the flow direction in critical places. In the Post-process class, students used the DEM file of Tholos site and GIS Software to effectively calculate Flow accumulation, direction (Fig. 31), sink areas and visualize the most probable stream network (Tomanis et al., 2017).

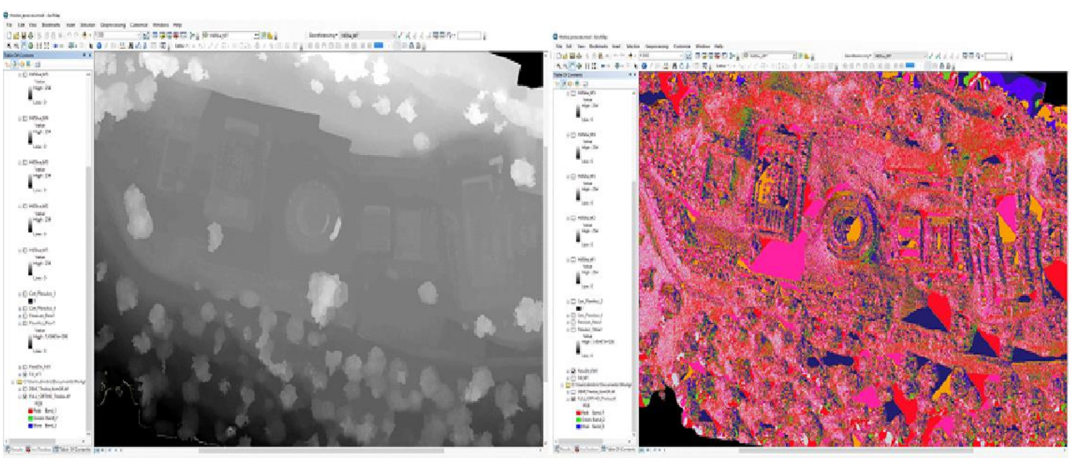


Figure 31. DEM of tholos in GIS Software and calculated Flow Direction

The exported DEM from UAS Photogrammetry had a spatial resolution of 6 cm and was imported in ArcGIS/ArcMap 10.3 Software for further analysis. Using the Hydrology tools provided in the Spatial Analyst Toolset, students followed the Fig. 32 to derive runoff characteristics.

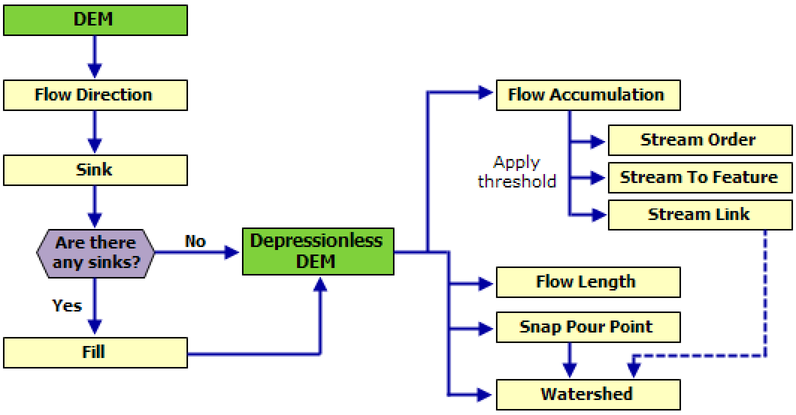


Figure 32. Hydrological modelling (Curtesy of ESRI ArcMap tools)

The provided DEM was adequate to provide sufficient resolution to identify even the smallest streams obtaining a useful tool cross referencing with existing drainage network (Fig. 33).

Figure 33. Stream network layered on Orthomosaic (Feature attributes include Stream link, order and length)

6.3.2 Shade calculations

A simple yet important task, is the ability to calculate shadow casts within the site. This calculation provides the archaeological site authorities with the required information to properly place:

- Signage, information stands unreadable under direct sun light
- Benches or rest areas and take advantage of natural shade
- Best observation angles/routes

With this scope DEM once again further exploited in GIS Software to calculate shades using as parameters the working hours and months of the site. In class the task was carried out using ArcMap 10.3 Hillshade Tool provided in the Surface/ Spatial Analyst Toolset (Fig. 34).

Figure 34. Hill shade relief with shadows visible form the beginning (light grey) to end (dark grey) of Sites working hour.

The resulted map, confirms what we witnessed on site, which the majority of visitors choose the southern route strafing on North-NorthWest avoiding the sun. This natural self-preserving instinct is responsible to make them to protect their eyes, yet most of them missed some important information signs at the Northern Route and could easily avoided with this simple derivative.

6.3.3 Total solar radiation

Solar radiation can affect the aging of monuments especially in conjunction with restoration/conservation treatments like laser cleaning (Klein et al., 2001). Furthermore, solar radiation is directly connected with vegetation growth as part of landscape architecture and maintenance (Stefanakis et al., 2010) as well as part of fracture filling that we will see later on.

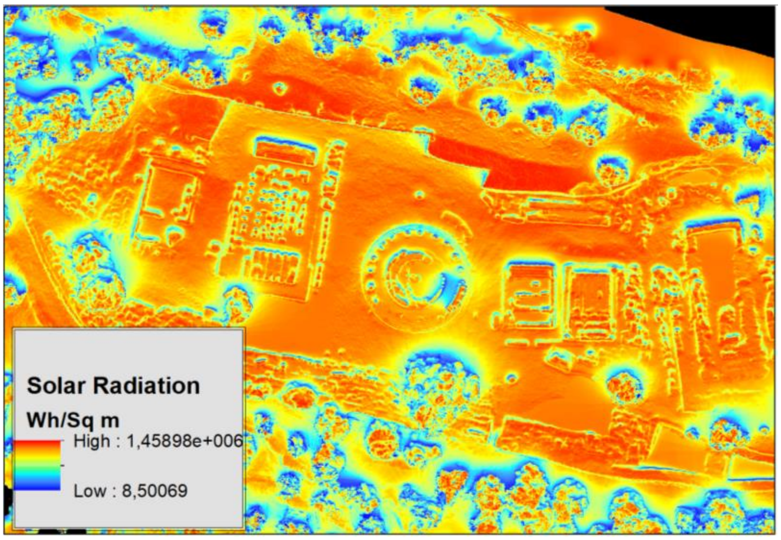


Figure 35. Insolation Map of Study area.

DEM was imported to GIS Software. Area Solar radiation tool & Points Solar radiation provided in the Surface/ Spatial Analyst Toolset was used to calculate:

- The Area Solar Radiation i.e. the insolation across site given per year, producing insolation map.
- Point Solar Radiation tool, i.e. the amount of radiant energy per year with month intervals for antiquities that require special attention.

In Fig. 35, one can notice the difference of irradiance at different orientation. Also, one may identify the bigger Canopy size of Olive trees positioned with North to South orientation at 30 degree angle.

Point Solar radiation tool, was helpful to visualize the irradiance difference among specific artifacts as well as understand the amount of variation during the year calculating month intervals. The spatial accuracy of given data along with the calculated figures, can be used as input to calibrate treatment instruments as mentioned, or used as reference in discoloration or other surface anomalies (Fig. 36).

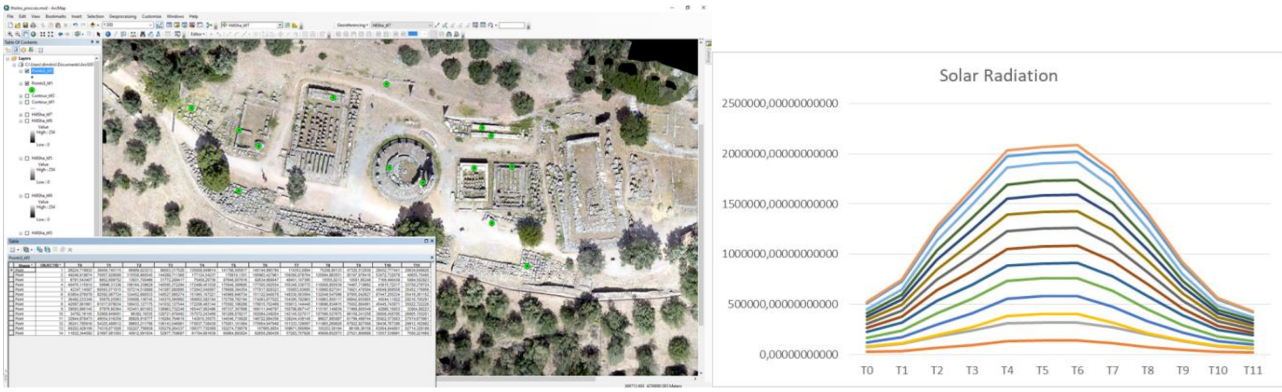


Figure 36. Selected Points and calculated solar radiation intervals, stored as attributes. Graphed values testify the difference of irradiance within the year.

6.3.4 Calculate retaining wall or rock discontinuities

Accentuating Multi-disciplinary, instructors gave an example of disseminating collected data for digitization purposes to other scholars. This example involves the usage of dense point cloud from geologist and rock mechanics engineers to enhance discontinuities studies used to analyze rock stability (Dewez et al., 2016).

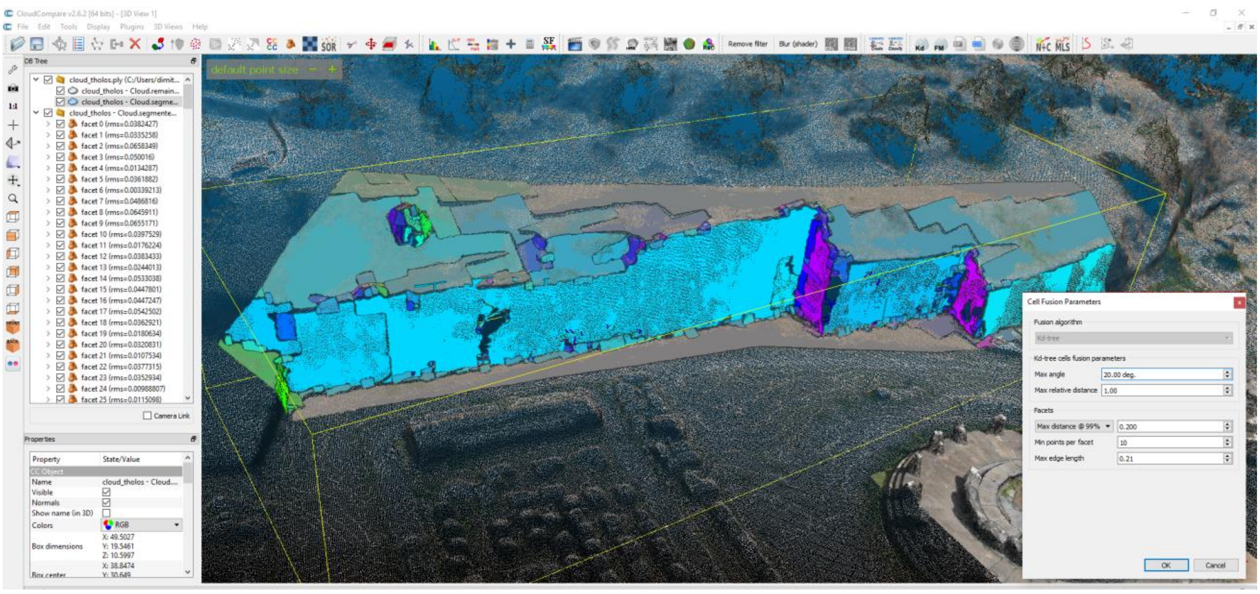


Figure 37. Calculated facets and Cell Fusion Parameters used in Cloud Compare software

For these purposes, merged UAS & Lidar Dense cloud imported to an open source software(Cloud Compare) for further analysis with the Facets plugin created and financed by Thomas Dewez, BRGM to Extract planar facets with a kd-tree (Fig. 37).

To quickly identify the principal facets orientations by geologist, a stereogram was calculated using the stereogram tool (Fig. 38). Data can be exported to GIS for further classification.

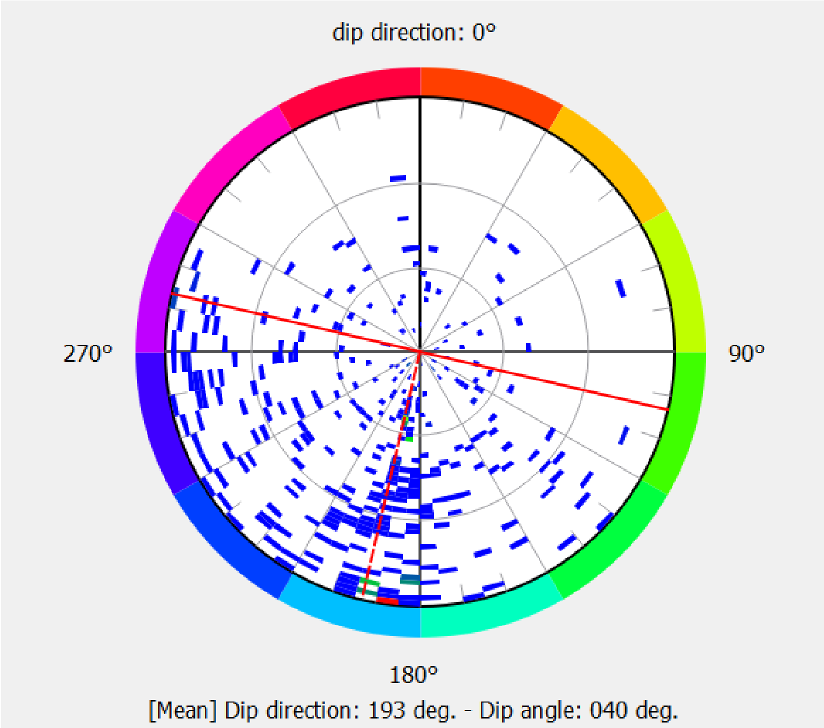


Figure 38. Stereogram of Facet orientations

The resulting SHP file will be composed of 2D polygons (Fig. 39). The attribute table contain various pieces of information for each facet:

- Index
- Center (X,Y,Z)
- Normal (X,Y,Z)
- retro-projection error (RMS)
- horizontal extension
- vertical extension
- surface of the bounding rectangle
- Surface
- Dip direction
- Dip
- Family index
- Sub-family index

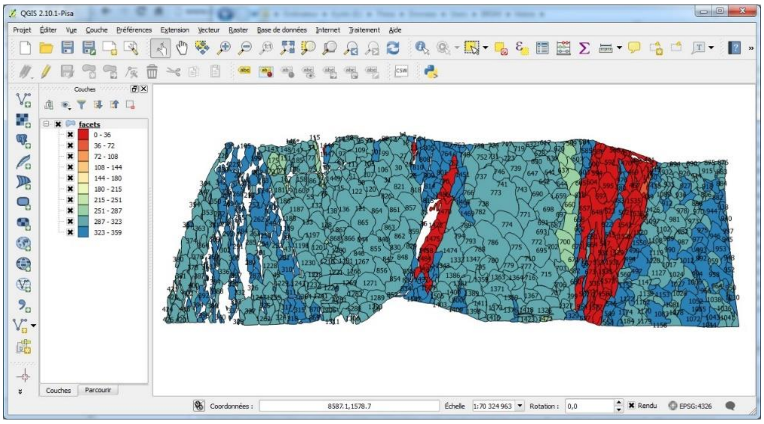


Figure 39. Facet SHP File, imported to GIS Software (QGIS 2.1) Courtesy of CloudCompare.org

6.3.5 GIS Multi-criteria analysis (Adding attributes to assessed information)

In each chapter students addressed a common task and undertaken it combining classical methods and modern tools effectively and efficiently. Digitization processes that used to be time consuming fulfilled in matter of minutes when data exploited in GIS environment. But still it was crucial to understand that the combination of all available technologies and their knowledge, when analyzed in time and space can produce a powerful decision tool support system, involving the integration of spatially referenced data in a problem solving environment (Malczewski, 2006; Liritzis & Vassiliou, 2006).

For this purpose we used digitized information of the study area (Fig. 40), adding literature quantitative and qualitative information in their attribute table using joining table method. Afterwards, using Geostatistical analysis, students were able to carry out an example of identifying connections e.g. between monument's azimuth and age, though azimuth is also related to celebrating deity at a particular date of the year.

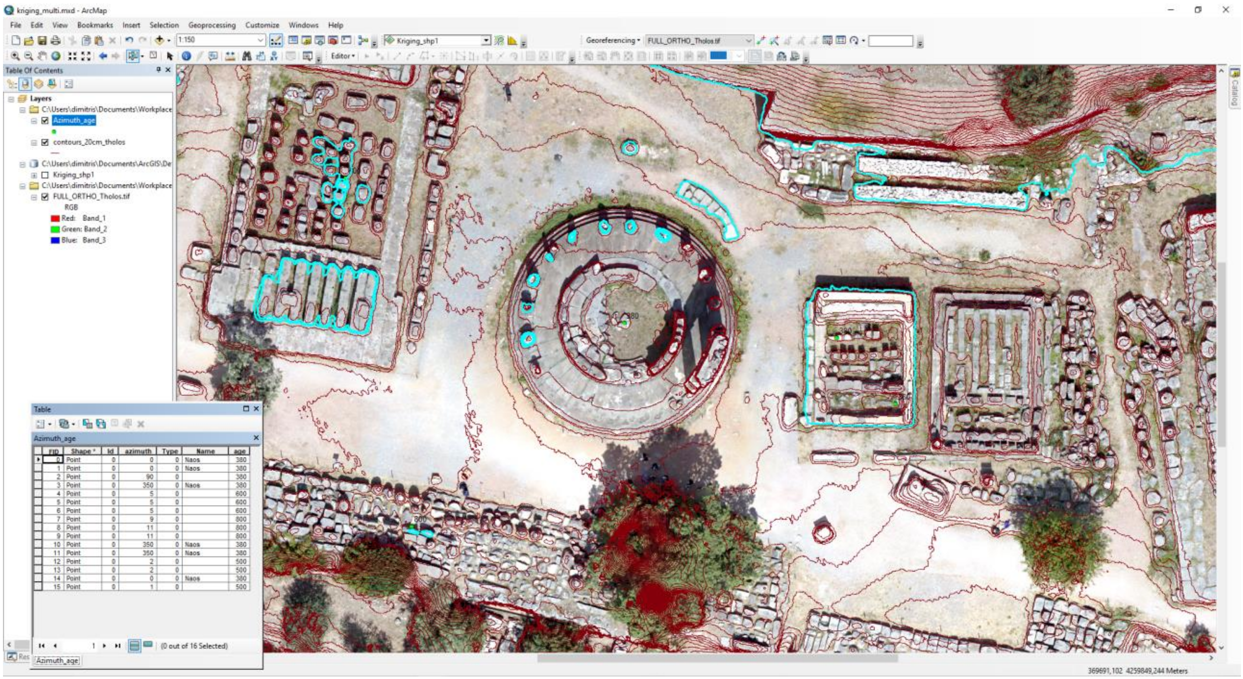


Figure 40. Digitized artifacts and attribute table containing Azimuth and Age information in ArcMap GIS Software

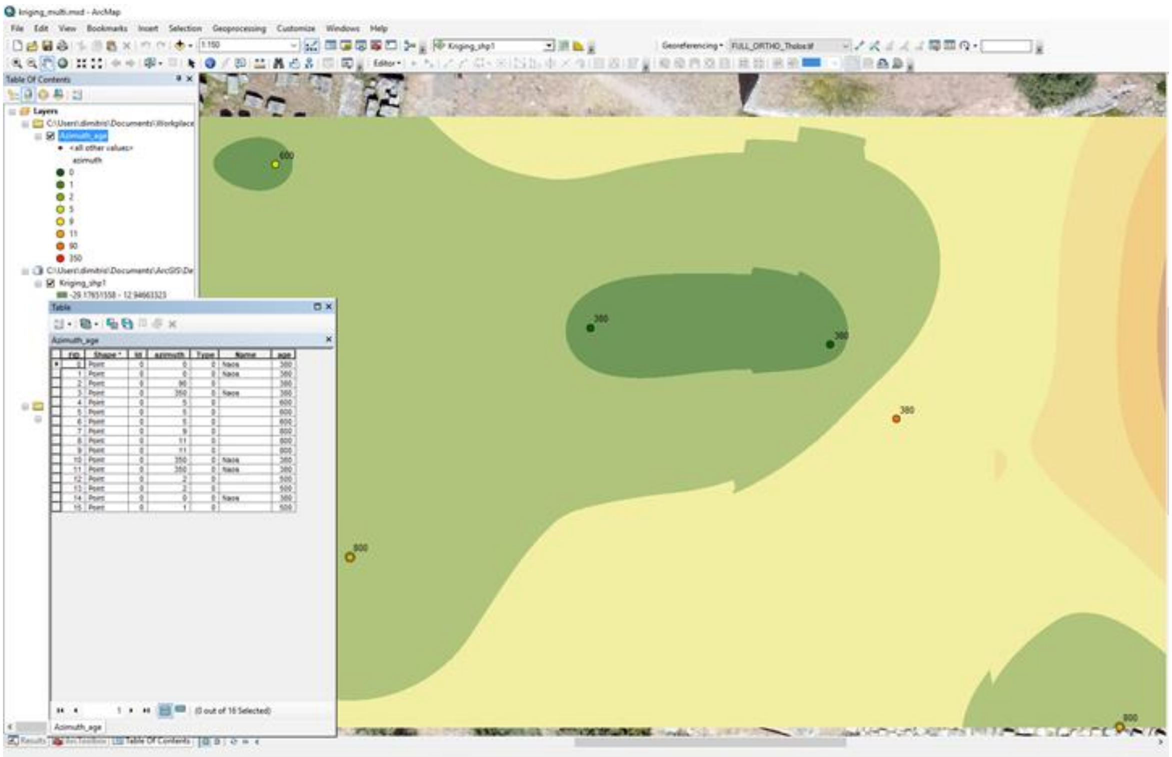


Figure 41. Calculated Surface model of Azimuth measurements and numbers that are extracted and Labeled Chronological data as spatially related with certain criteria to the azimuth.

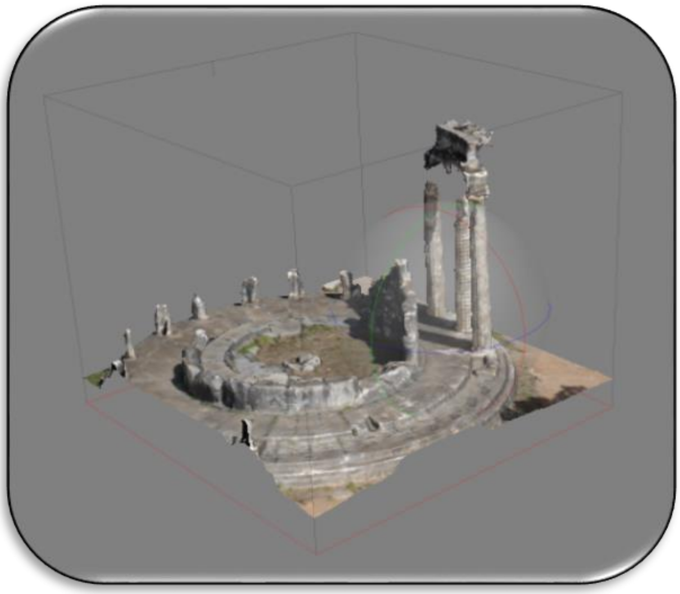
In GIS Software, students used spatial interpolation tools under Geostatistical analysis toolset (ArcMap 10.3) to interpolate Azimuths (Fig. 41). Furthermore, using identity tool, they were able to extract and label age information as spatially related with certain criteria to the azimuth, thus enable them to identify regions of the study area from different eras. Noticeably from Fig. 41, we can identify a pattern regarding age of construction, though further analysis can be accomplished to join azimuths and chronological estimation as performed in archaeoastronomy science. This was performed as an exercise having in mind that similar azimuths do not necessarily imply same age, but it is important to get through azimuth the orientation of the monument and angular altitude of skyshine for archaeoastronomical orientation purposes (Liritzis & Vassiliou, 2002). Azimuths are determined by digitizing any two points along the orientation of a monument. Angular altitude is also determined by digitizing two specific points along the orientation of the monument the one being at the monument and the other at a distance of such a ground elevation as to maximize the altitude angle.

7. EDUCATIONAL PRODUCTS FOR GAME ENGINES

In our days with the proper use of digital technologies, the specific objectives of communication and promotion of cultural content has been systematically studied. This scientific area is called Digital / Virtual Heritage (Addison, 2000).

According to Addison (2000) there are three major domains in virtual heritage:

- 3D Documentation: everything from site survey to epigraphy
- 3D Representation: from historic reconstruction to visualization
- 3D Dissemination: from immersive networked worlds to 'in-situ' augmented reality.



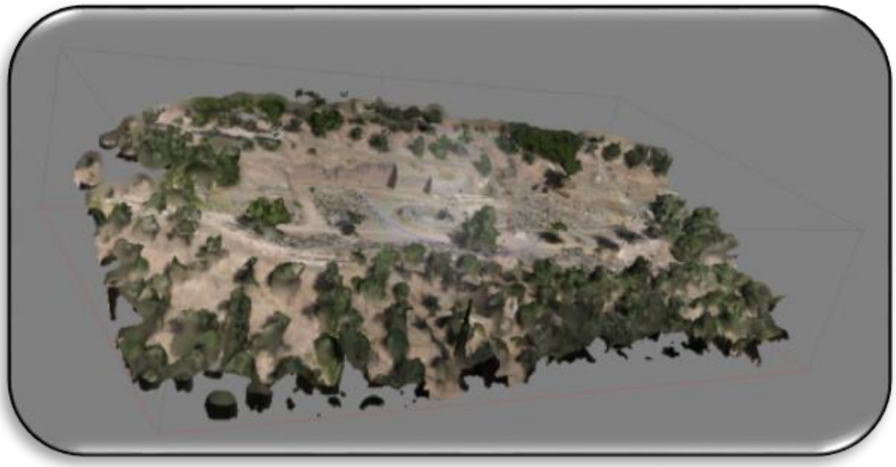


Figure 42. 3D models of the monument Tholos made by SfM.

The new possibilities offered by the technology allow for the 3D digitization of spaces, monuments and artifacts, their virtual reconstruction in the form they were supposed to have in the past, their digital imaging, their enrichment with simulation elements (e.g. virtual characters), user interactions (navigating and manipulating objects), viewing additional information and much more.

Structure from Motion (SfM) photogrammetric range imaging technique has been used, as shown in Fig. 42, for processing all photograph data, which created the 3D models below of the entire Tholos monument.

Elements such as storytelling, testing, gamification, or even integrating all into a serious game, could lead to a more fun process, increasing the mobilization of users and leading to better learning outcomes (Mortara et al., 2014).

For example, Unity3D game engine software (Fig. 43), could be used to develop a serious game using the 3D models, or a virtual presentation with game and augmented reality elements presenting the ancient life into the environment of Pronaia Athena and the sanctuary using learning tasks.

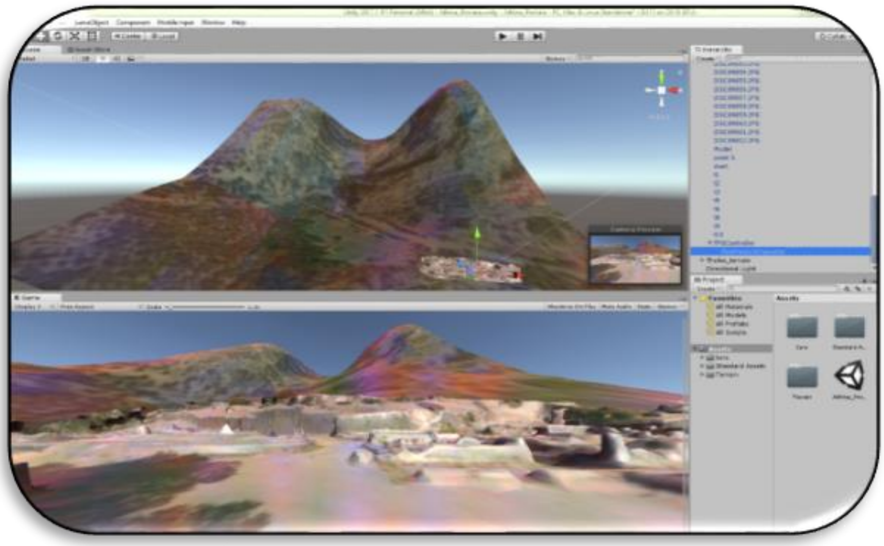


Figure 43. 3D models inside Unity3D.

Then evaluations with representative users in many scenarios should be designed and implemented using different teaching approaches to draw conclusions about the suitability and usability of the various design choices as well as the overall contribution of such applications to the objectives dissemination and promotion of cultural heritage.

8. CONCLUSIONS

There was a quite successful effort to educate postgraduate students in the use of all kinds of technologies for the digital reconstruction of the Tholos archaeological structure in Delphi.

Surveying technologies such as UAS, Total station, digital camera, Lidar scanner and GPS were used in situ to collect all necessary data and most important it was given the opportunity in each individual student to participate by hands on in most such processes. Consequently, back in the classroom it was used most advanced technologies in terms of software and methodologies such as photogrammetry for data processing. Data processing in the classroom gave also the opportunity to each individual student to work with hands on in most advanced software such as Agisoft Photoscan and Structure from Motion (SfM).

The most important part of this project was the real application of Tholos monument and the use of all processing results for its geometric restoration and the site maintenance. The cooperative communication between all the experts and the supplementary nature of such projects proved essential and necessary. The participating students coming from different disciplines and having different backgrounds had the opportunity to collaborate together and learn how to communicate with each other. In addition, they came in contact with modern and contemporary methods and derivatives, learning their application, utility and necessity. This project formed an innovative learning outcome for graduate students, offered useful data to local archaeological authorities for use in restoration, protection, preservation, conservation purposes and highlighted the interdisciplinary value of archaeological sciences concerning digital cultural heritage.

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