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Use of various surveying technologies to 3D digital mapping and modelling of cultural heritage structures

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GIS
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ΕΡΓΑΣΤΗΡΙΟ
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R S L U A

Use of various surveying technologies to 3D digital mapping and modelling of cultural heritage structures

Presentation by

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digital reconstruction of archaeological site
for restoration, maintenance and protection purposes

- Purpose: train graduate students

- Project: Delphi4Delphi (archaeological site of the Tholos monument and the surrounding area in Delphi Greece).

- technologies used:
  - GPS to establish the reference system,
  - total station to measure a number of ground control points,
  - UAS to map precisely the surrounding area together with the structure,
  - close range photogrammetry and Lidar scanner to map the vertical surfaces

- Processing: to created enough point cloud for precise mapping
  - expand the architectural design to precisely restore the entire Tholos monument.
  - Use digital data for construction of 3D terrain DEM and 3D models
  - Use GIS with DEM and 3D models to derive drainage features, Sun orientation and geoprocessing
  - Insert 3-D models into Game Engines to create of educational scenarios.

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Class of
Graduate
Students

Diagram for restoration and maintenance
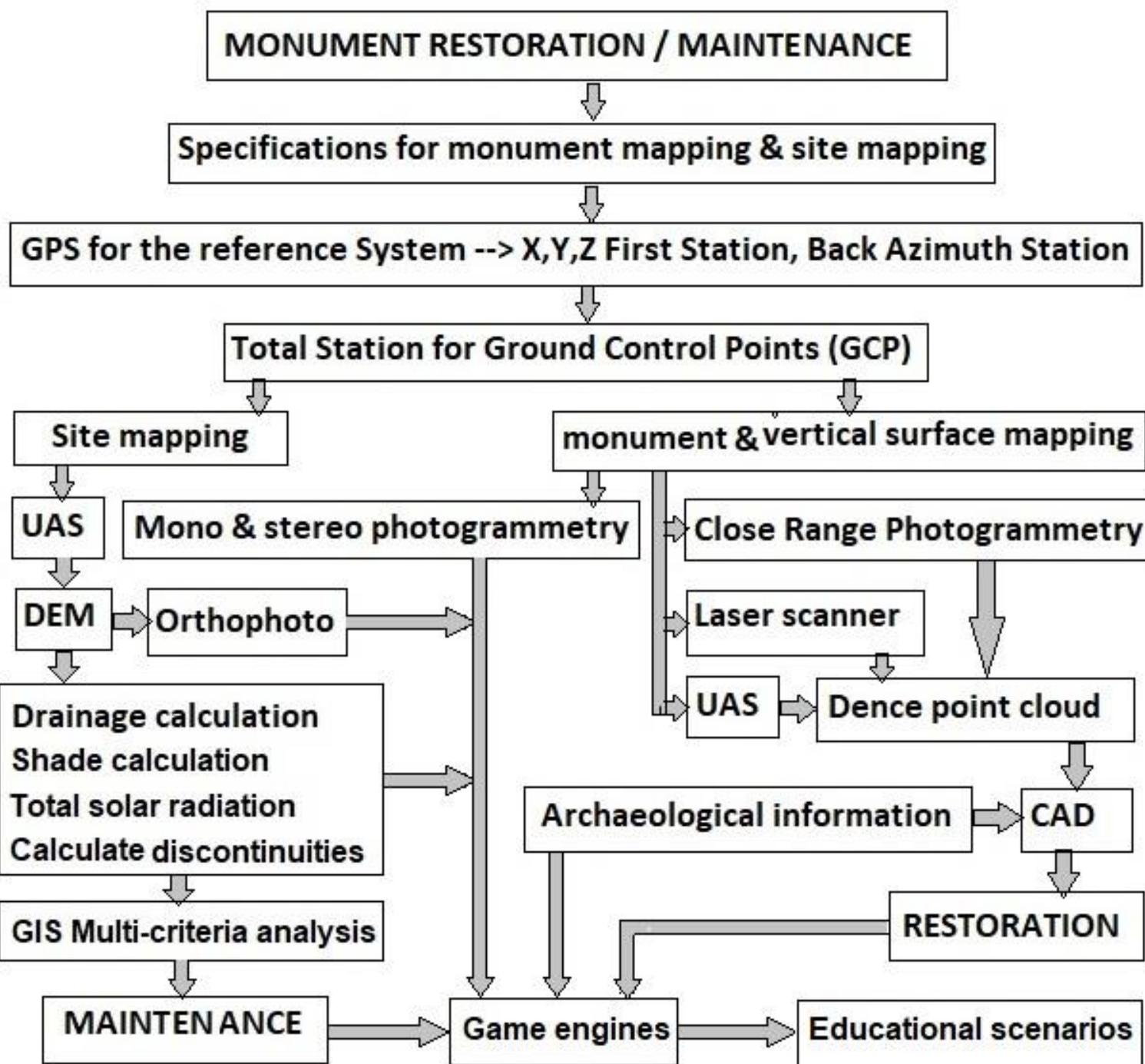
Tholos

Tholos is part of **sanctuary of Athena Pronaia**, and its importance relates to those appealing to Apollo via priestess Pythia for an oracle. Tholos structure was constructed sometime between 400-375 BCE by architect, Theodorus from Phokaia in Asia, **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.** 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.** 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. 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.

Tholos monu-ment in Delphi Greece

Out of 20 columns only three have being restored

Project design

Design specifications

- The reference system: EGSA-87 Greek Grid with an accuracy compatible to Google map.

- 3-D mapping of the wider area with horizontal and vertical accuracy of ±5 cm by UAS technology.
  - Final product: DEM and orthophoto

- Mapping of vertical surfaces of the Tholos structure and a vertical wall by Close range photogrammetry and laser scanner. Expected accuracy: ±1 cm.

- Control points for UAS, close range photogrammetry and laser scanner by total station. Expected accuracy: ±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.

REFERENCE SYSTEM AND TOTAL STATION SURVEYS

- Measure by hand held GPS two points A and B.
- Use point A as the first station to be occupied by total station
- Use point B to compute a backsight azimuth [grads].

XA	369730	YA	4259870	
XB	369650	YB	4259876	
AzAB	304.76572592091	dAB	80.2246844805263	
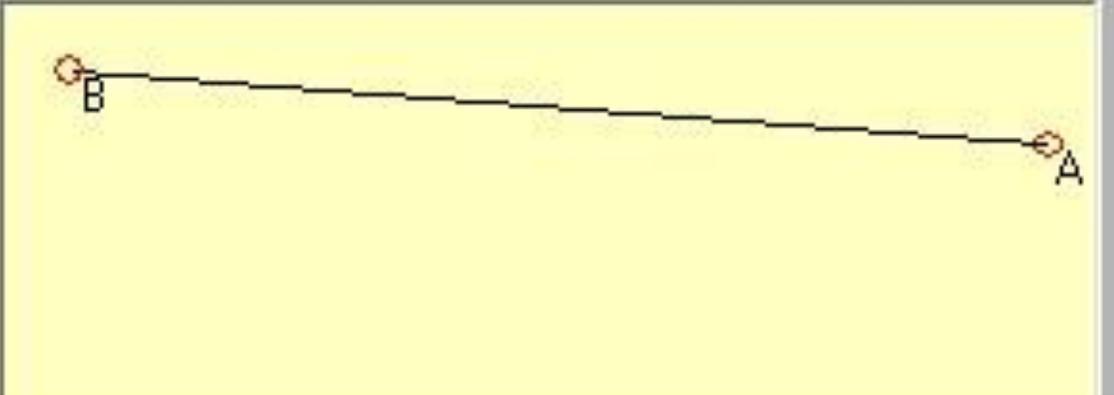
The azimuth and the distance was computed by an in house developed educational software
http://www2.env.aegean.gr/labs/Remote_sensing/EnglishBlock/Software/Cogo_Jnh.rar

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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

UAS Control Points

Scanner Control Points

Photogrammetry Control Points

Location of control points

(a) for UAS/scanner
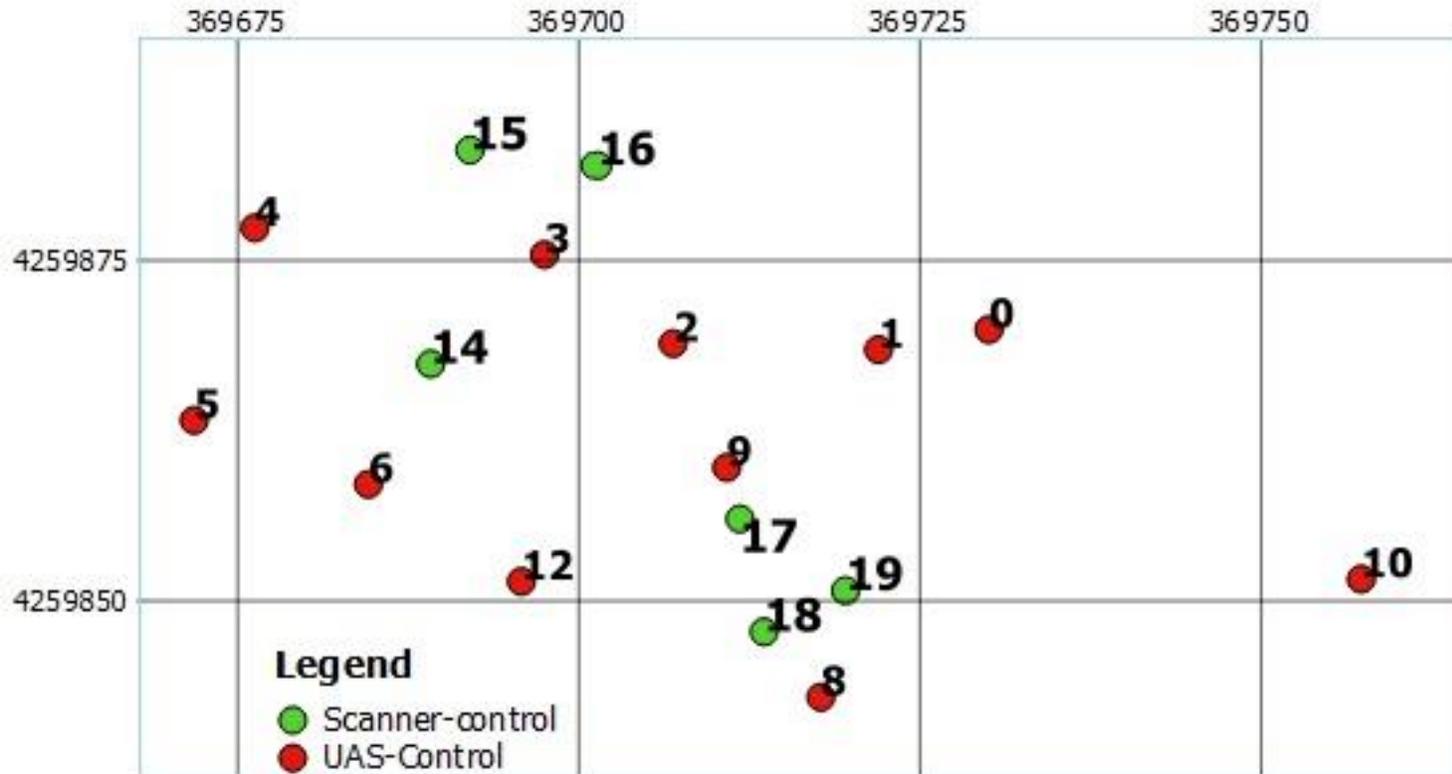
(b) on the wall
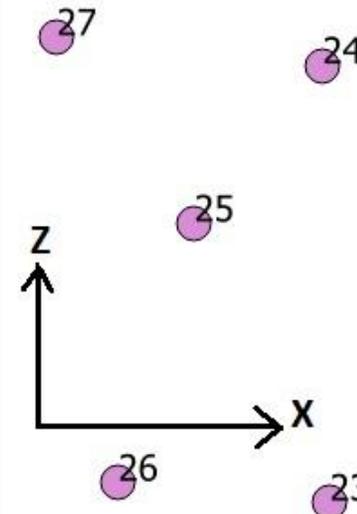
(c) on the columns
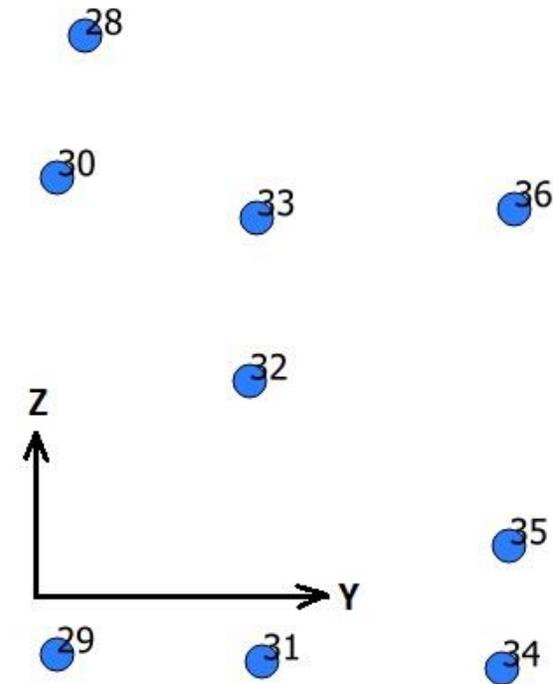
Targets for UAS, Scanner and on the wall

CLOSE RANGE PHOTOGRAMMETRY SURVEYS

A sample stereopair of the Tholos

LASER SCANNER MEASUREMENTS

Leica Scanstation 2

The scanner positions were determined carefully having in mind the following rules :

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

The Point Cloud after registration
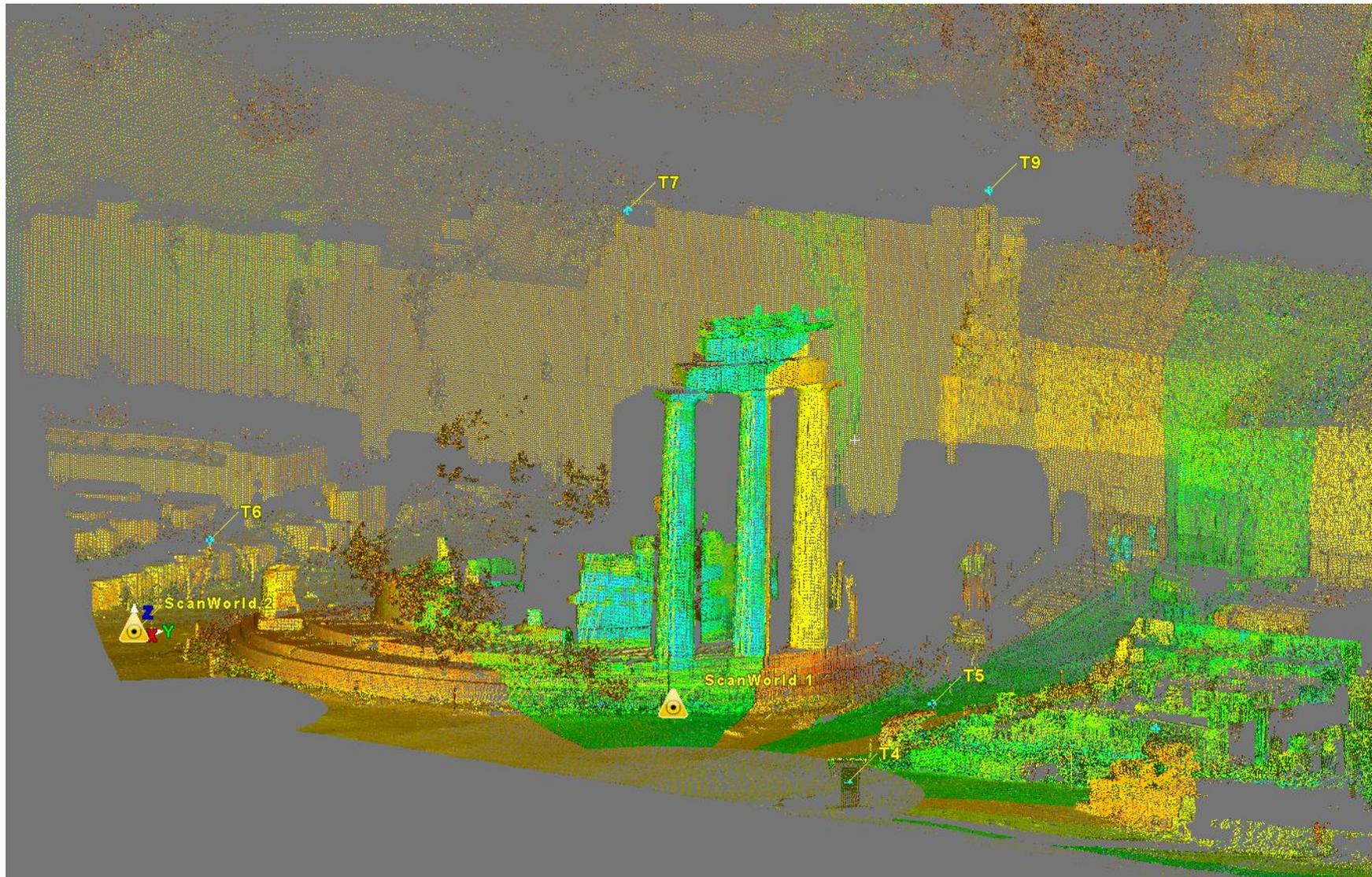
UAS SURVEYS

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

1. provide a wider area digital basemap/orthophoto for various related tasks

2. Obtain a high detailed Digital Surface Model (DSM), to be used for terrain analysis, survey measurements or photorealistic modelling background.

3. Provide significant detailed 3D Point cloud for the study area and especially for regions that are difficult or unattainable with laser scanning

4. Capture scenery and artifact texture in desired detail, to provide color information for laser scanning or unattainable places with close range photogrammetry.

5. Immerse Students to modern technologies and methods, emphasizing bottom-up approach in Concept of operations

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Concept of Operations (CONOPS)

Flight Planning

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 m²
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

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

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/)
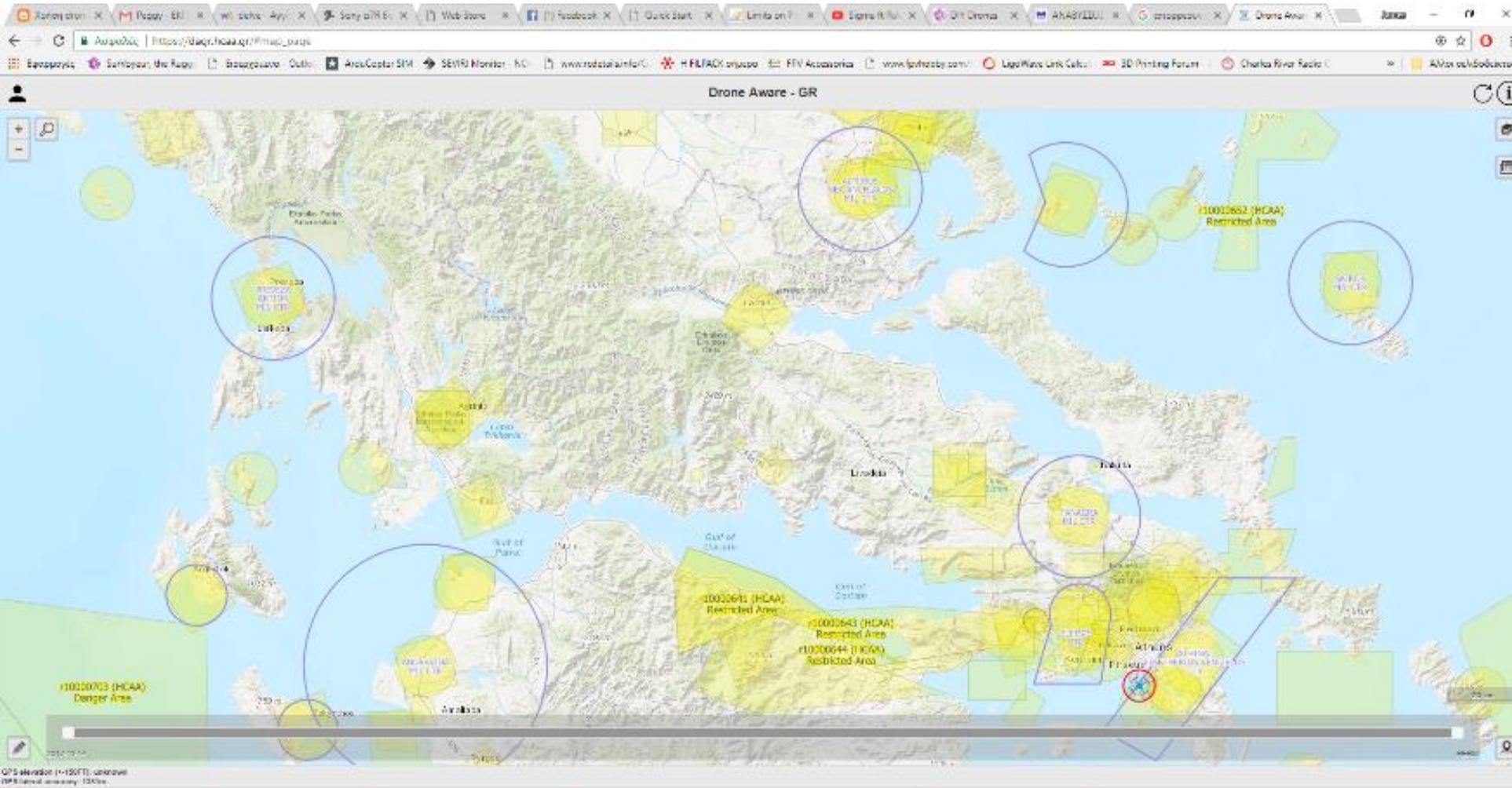
Drone Aware - GR (DAGR) is a real-time UAS (drone) information system for Greece developed by the Hellenic CAA (HCAA). DAGR provides situational awareness to UAS pilots and operators by informing them about flight limitations and letting them submit flight requests. The system provides additional resources concerning the acceptance or the rejection of a flight request, aeronautical data and other relevant information.

UAS Data Processing

Image Geotagging and attribute matching

logging capabilities of the Avionics equipment along with GCS Software are used to match photos and appropriate information needed from IMU and GPS:

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

Aerotriangulation

- Agisoft Photoscan Professional licenses were donated to the Post Graduate Program and it was used for data processing.

Resulted geo-tagged images and position error estimates.

Mission Planner Geotagging tool interface

Geo Ref Images

C:\ProblemGeoTag\70.log — Browse Log

C:\ProblemGeoTag — Browse Pictures

- ● Time offset
- ○ CAM Message Synchro

Seconds offset: -2493750 — Estimate Offset — Shutter lag (ms): 0

CAM Message Offsets
- GPS Millis: 1
- Lat: 3
- Lon: 4
- Alt: 5
- GPS Week: 2
- Head: 8
- Roll: 7
- Pitch: 6

GPS Message Offsets
- GPS Millis: 2
- GPS Week: 3
- AMSL Alt: 9
- Lat: 6
- Lon: 7
- Alt: 8

ATT Message Offsets
- Head: 7
- Roll: 3
- Pitch: 5

Dir fov: 130 — Rotation: 200 — Cross fov: 90

☑ Use AMSL Alt

Pre-process >> Location Kml >> GeoTag Images

Photo SAM_0390 PROCESSED with GPS position found 0 ms away
Photo SAM_0391 PROCESSED with GPS position found 0 ms away
Photo SAM_0392 PROCESSED with GPS position found 0 ms away
Photo SAM_0393 NOT PROCESSED. No GPS match in the log file. Please take care
Photo SAM_0394 NOT PROCESSED. No GPS match in the log file. Please take care
Photo SAM_0395 NOT PROCESSED. No GPS match in the log file. Please take care
Photo SAM_0396 NOT PROCESSED. No GPS match in the log file. Please take care
Photo SAM_0397 NOT PROCESSED. No GPS match in the log file. Please take care
Photo SAM_0398 NOT PROCESSED. No GPS match in the log file. Please take care
Photo SAM_0399 NOT PROCESSED. No GPS match in the log file. Please take care
Start Processing
Done

⇐ Selection of Log file
⇐ Selection of Pictures folder
⇐ GeoTag Mode
⇐ Time offset Estimation and Shutter Lag
⇐ Log Offsets
⇐ Camera FOV info
⇐ AMSL or AGL Altitude selection
⇐ Action buttons
⇐ Process messages
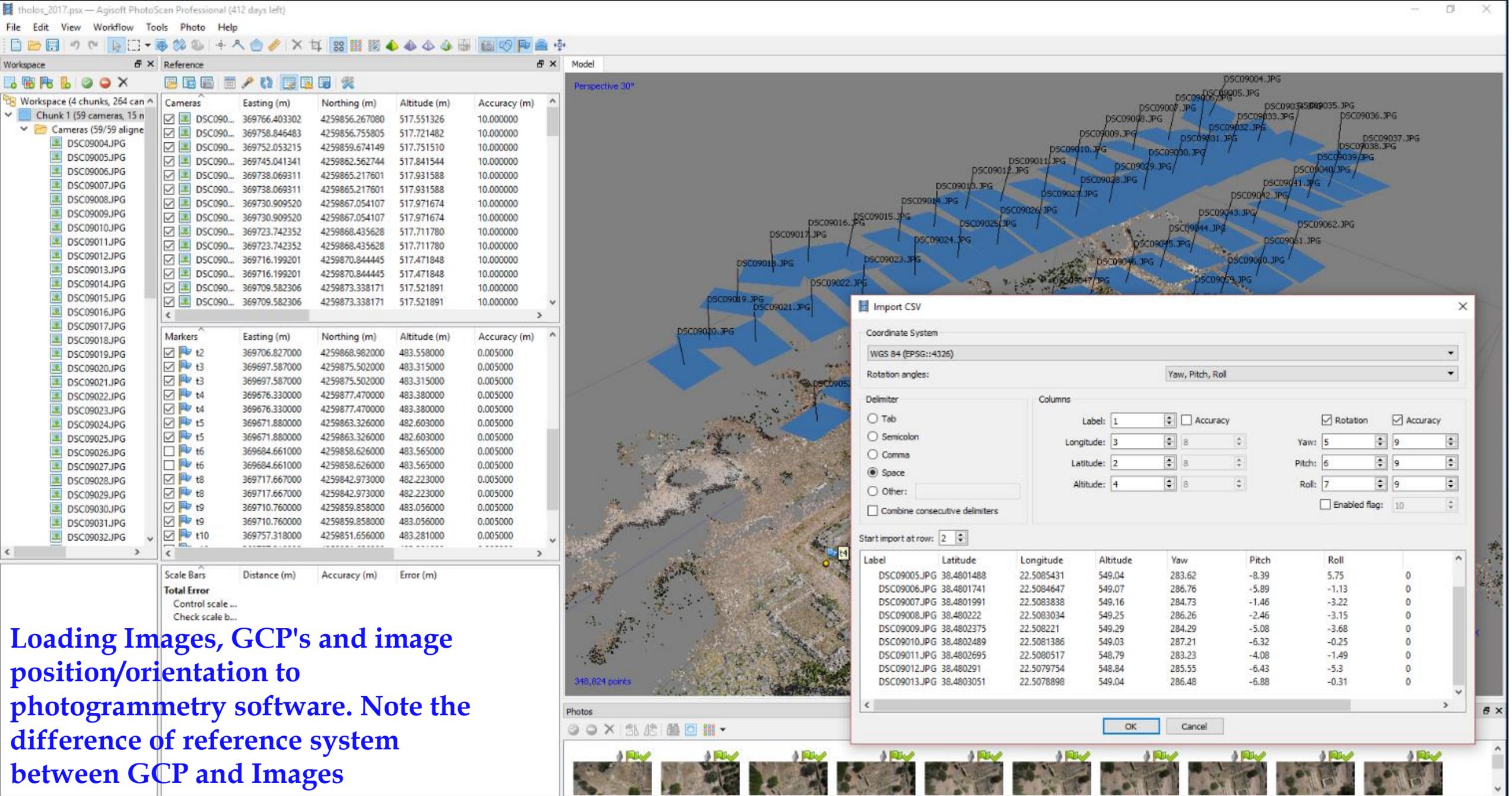
Loading Images, GCP's and image position/orientation to photogrammetry software. Note the difference of reference system between GCP and Images

Control point (GCP)

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

Dense Cloud Generation (5.417.319 Points)
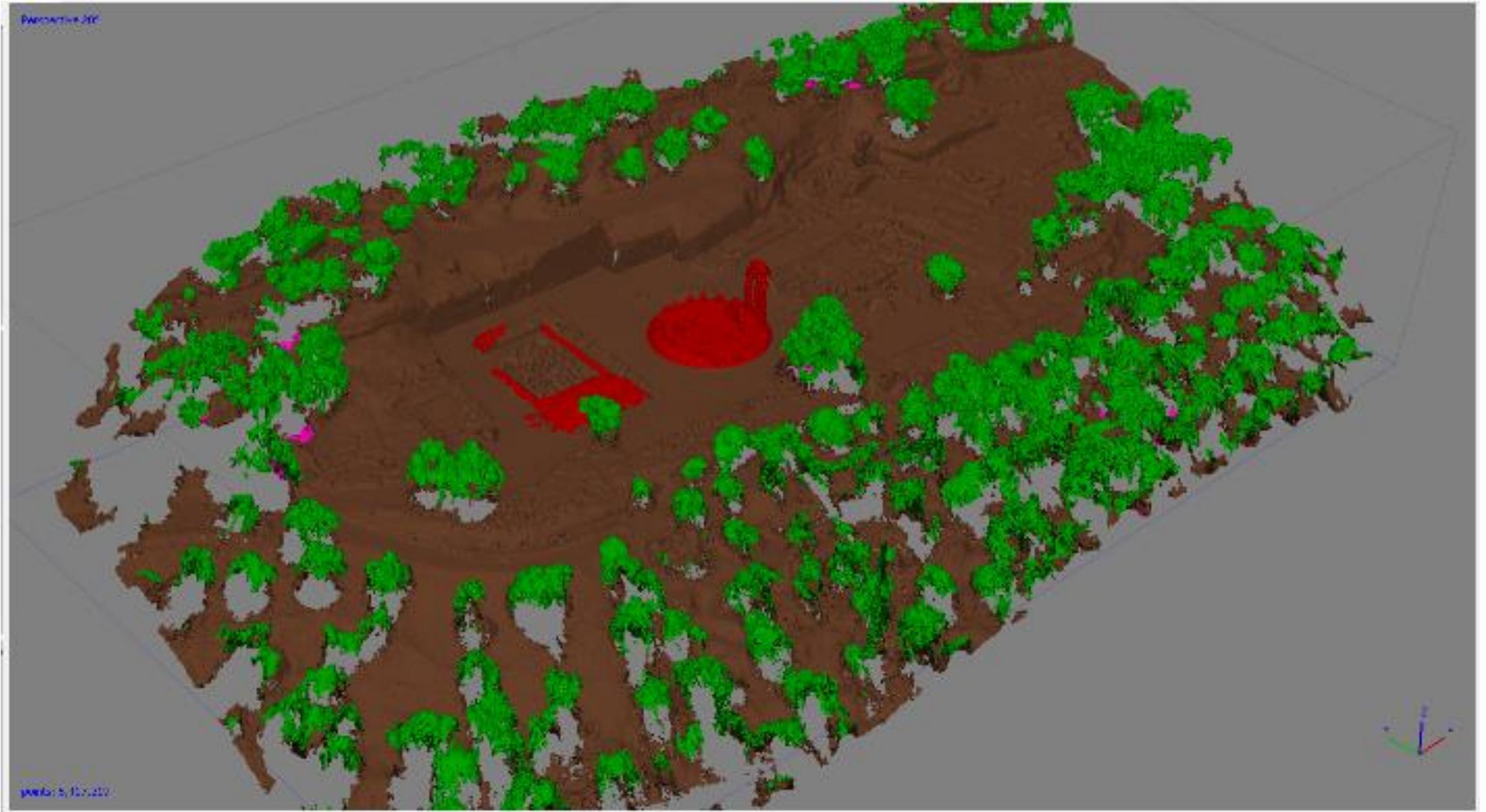
Classified Dense Cloud to: Ground, Vegetation and Structures

Digital Elevation Model (DEM) and Orthomosaic

- Each 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.

- Following the mandate aerotriangulation processes, create Digital Elevation Model (DEM) and Orthomosaic.

  - DEM creation uses as input the Dense Cloud points but the Dense cloud contains information from both Terrain, building and vegetation. In the case of Tholos we needed to calculate one DEM to include Vegetation for shadows, wind, micro-climate analysis and one more DEM that is based upon terrain points for further exploitation like drainage analysis, slope, contour maps etc.

DEM Variants, with and without vegetation, respectively
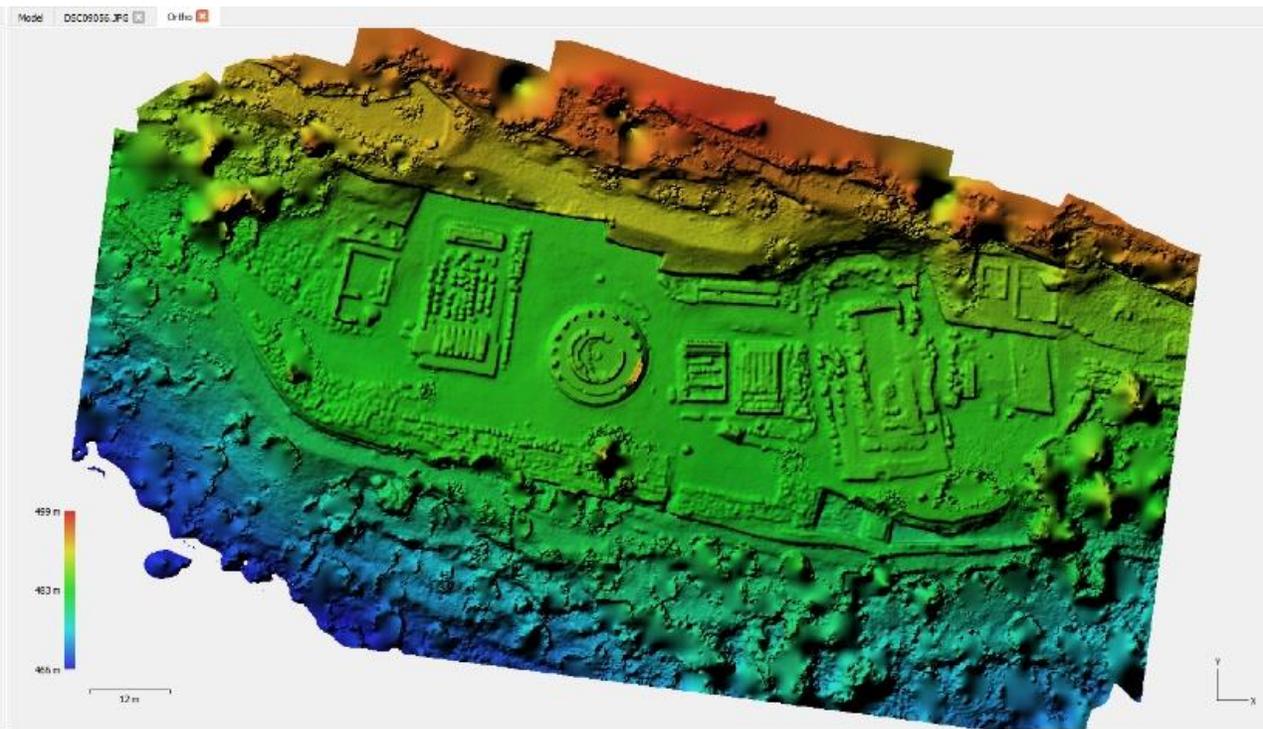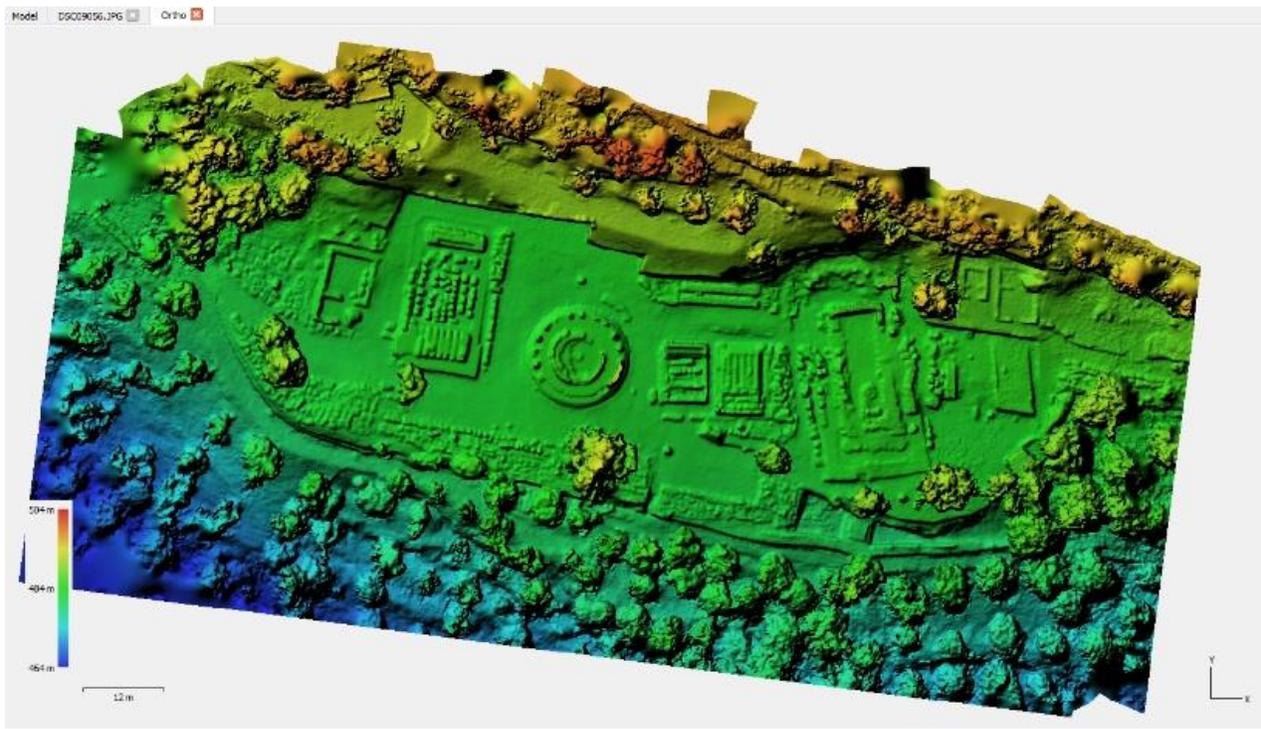
Dense Point Cloud

- Using Dense Point Cloud manipulation and classification tools, we were adept to classify the dense point cloud to every desired class enabling export of desired variants.

- Consequently, we proceed to the first final of derivatives, which is the orthomosaic.
  - For this process photogrammetry tools take into consideration the primary images and DEM, to apply the geometrical transformations and image assignments.
  - 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

Study area orthomosaic and seamlines of assigned imagery
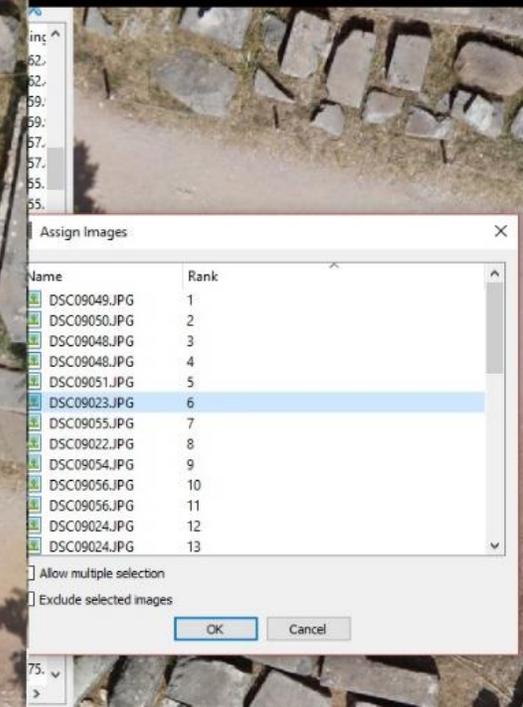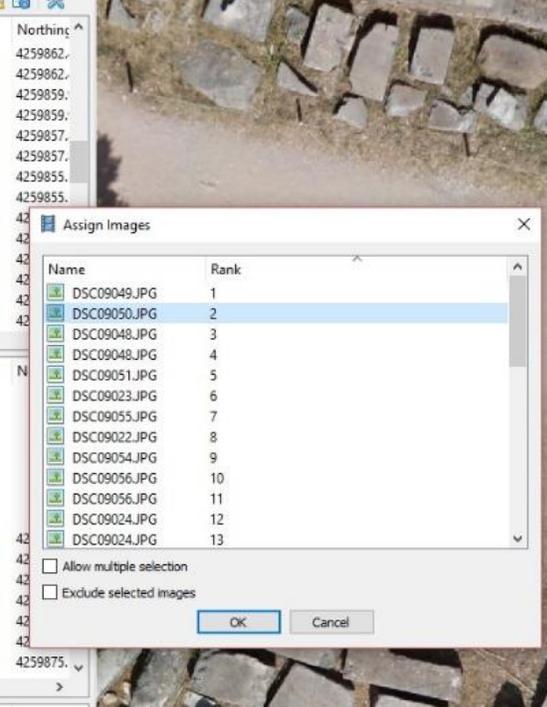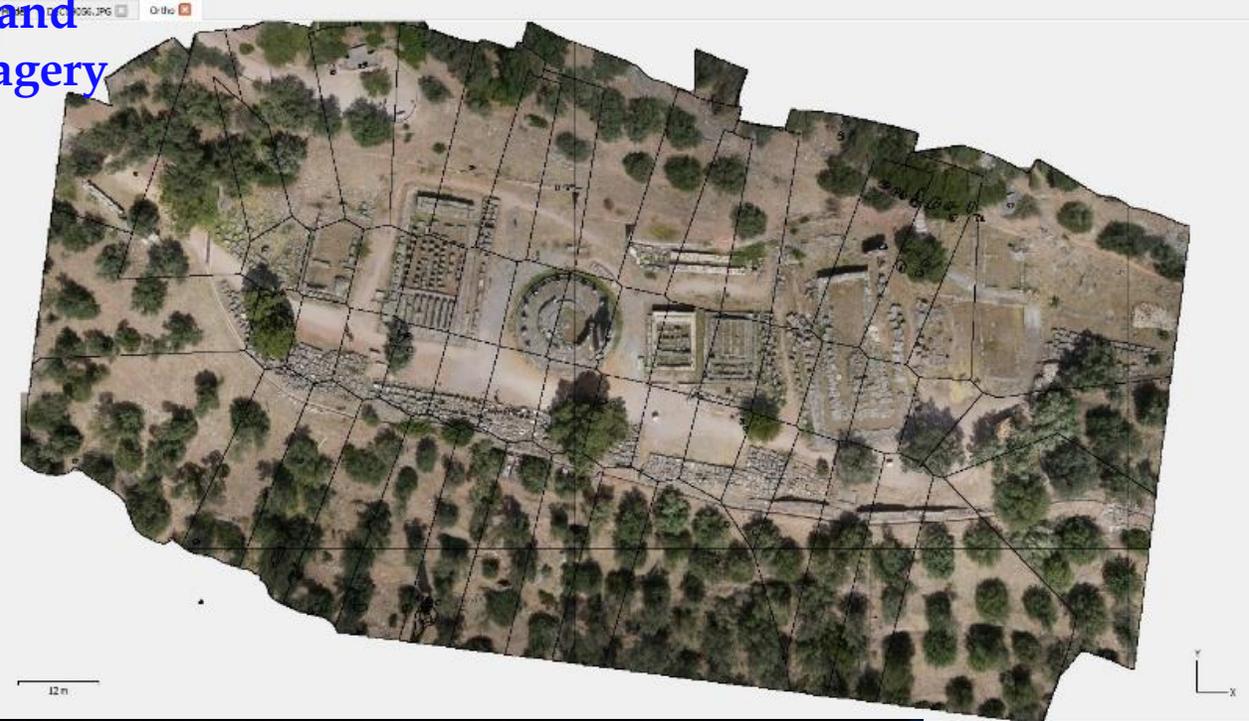
Manual image assignment to the orthomosaic process, to remove unwanted moving figures

Final UAS products

- Disseminate 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.)

RESTORATION PROCESS

Use UAS Derivatives to:

- Merge data and other information for restoration
- calculate drainage and recommend appropriate actions (GIS)
- calculate Solar Radiation, sunlight and shadow casting to improve/optimize siting, like visitor signage, security posts etc. (GIS)
- 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. (GIS)

Natural/human disaster: a detailed 3D survey could act as reference for restorations

MERGE DATA-INFORMATION

Use: Open source **Cloud Compare Software** (http://www.danielgm.net/cc/) to merge data from different sources (vantage points).

Align two point clouds the one from laser scanner and the other one from UAS using common tie points.

- 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

Align two point clouds the one from laser scanner and the other one from UAS using common tie
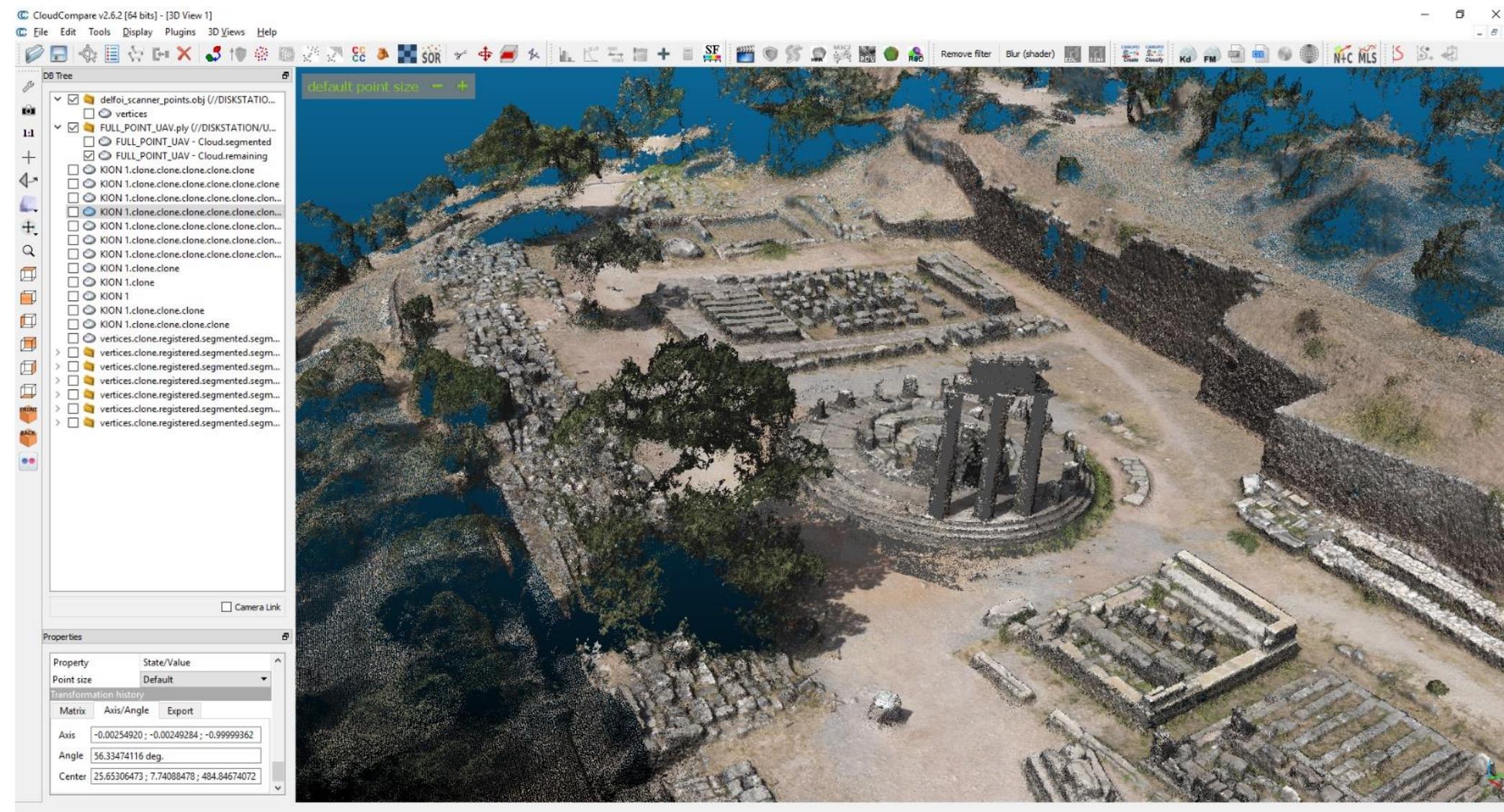
Importing Point Clouds from UAV and Lidar Scanner into Cloud Compare Software and doing the alignment by using Control points

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

Abstracted columns to be aligned
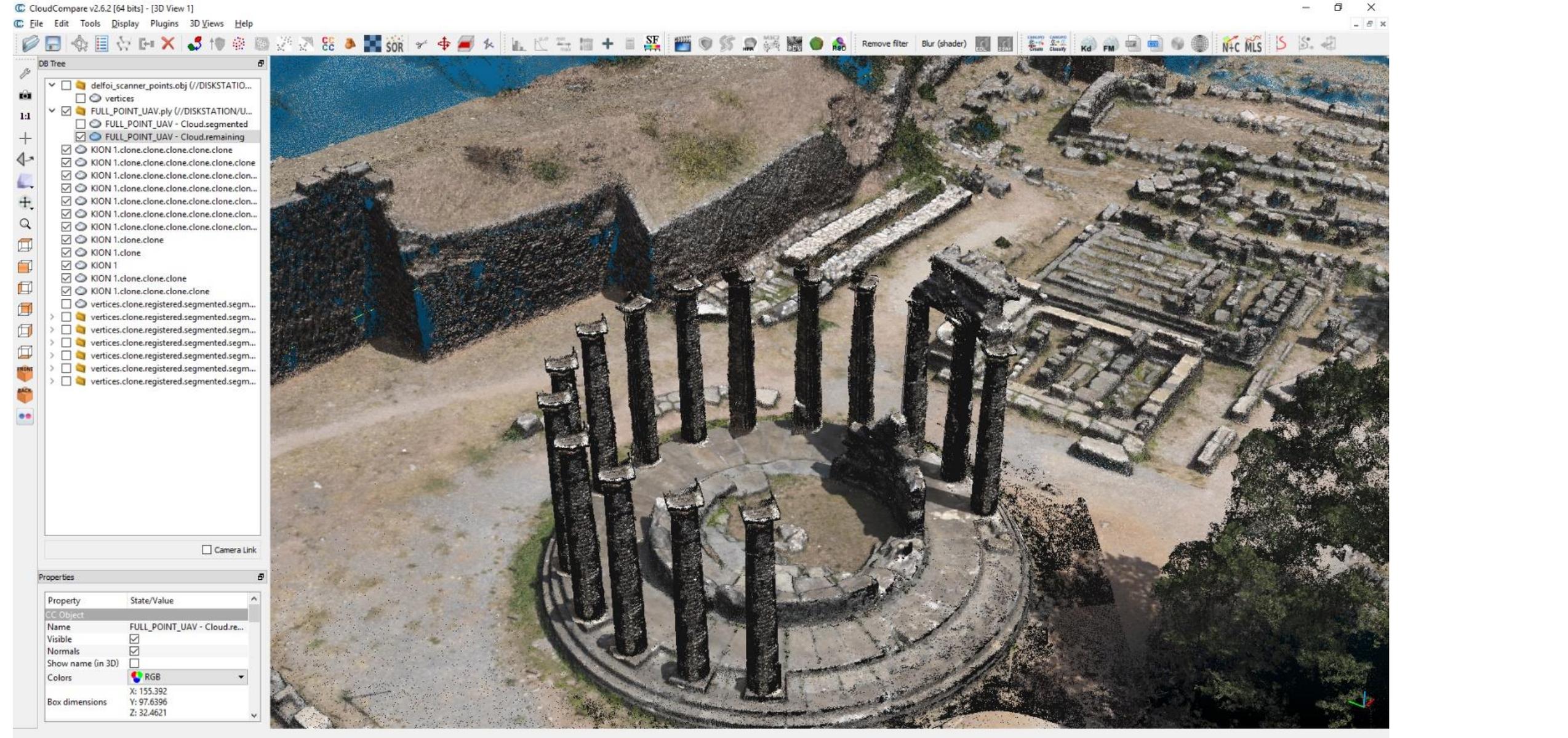
Column restoration process

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

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
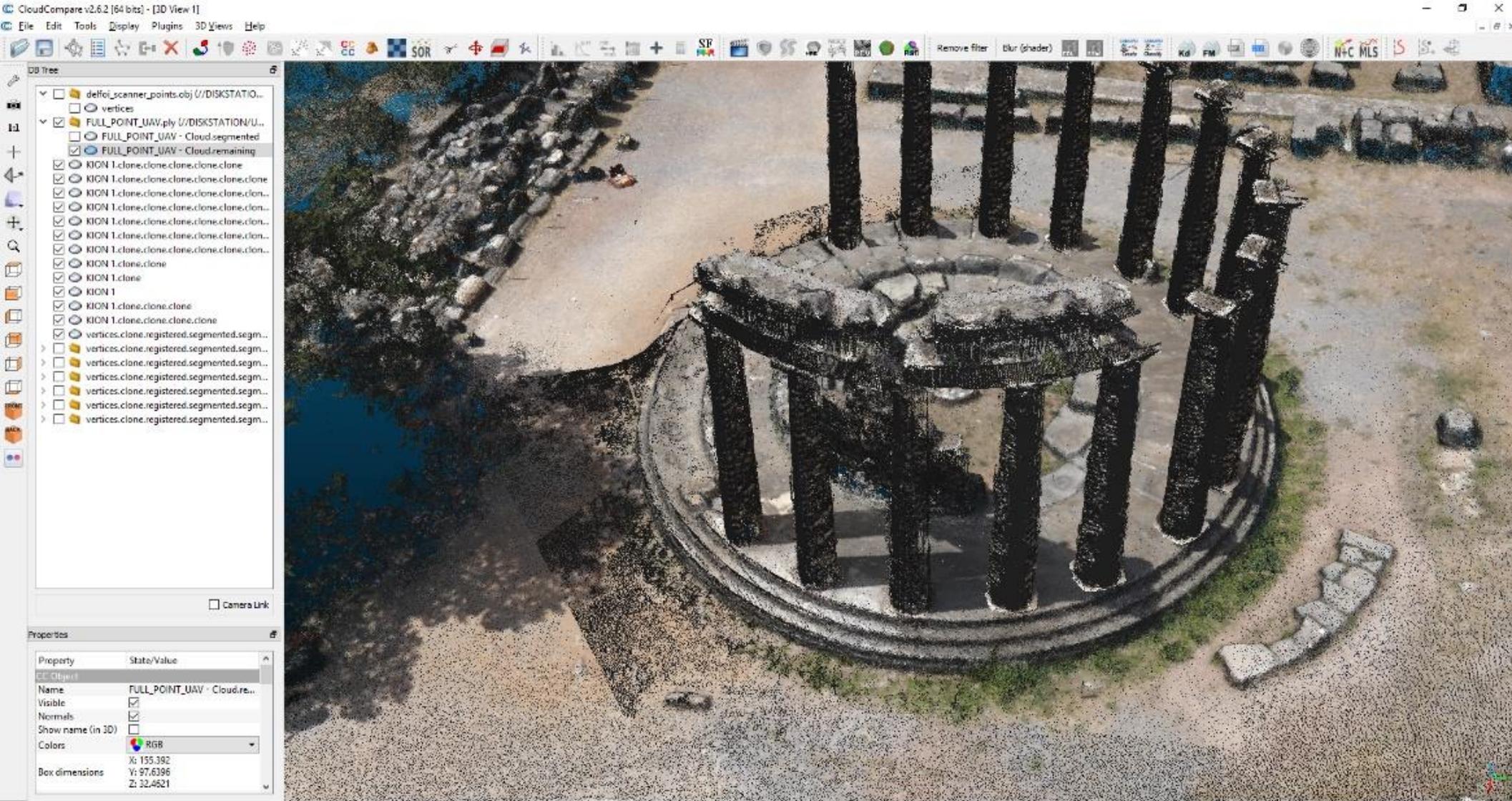
Pediment reconstruction
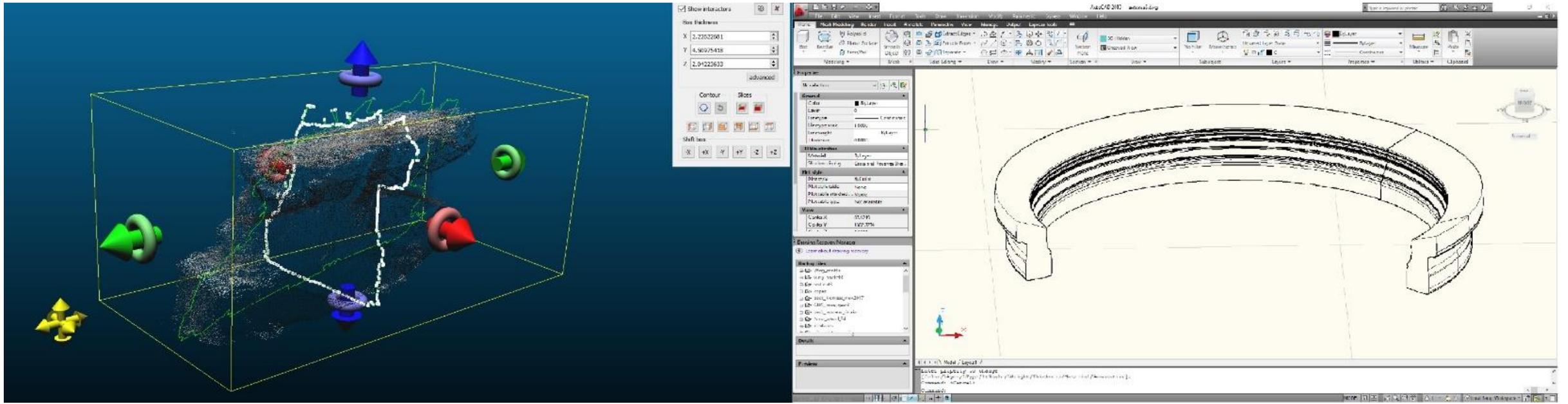
Export cross-section to CAD(eg DXF). Identify Radius and Arc. Revolve Cross Section

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. 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).

Finalized Columns and Pediment Structures
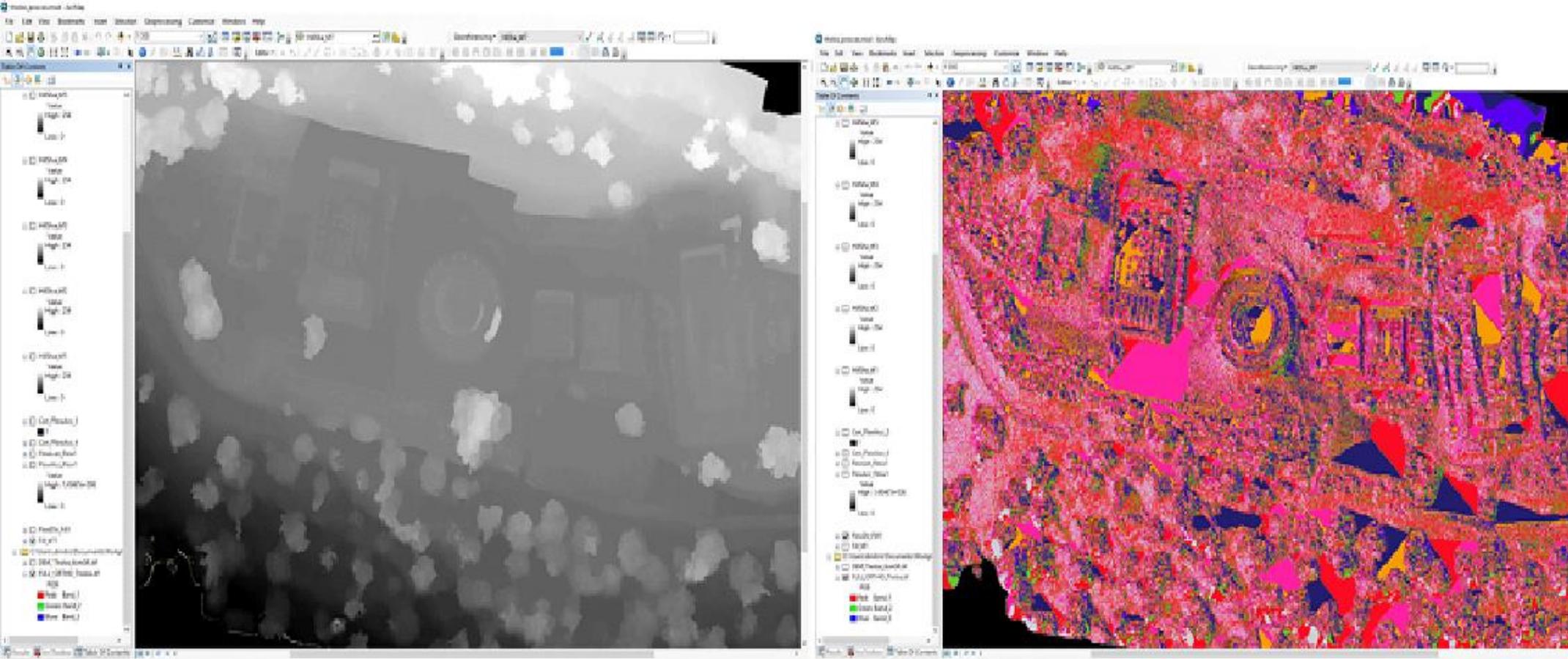
DEM of tholos in GIS Software and calculated Flow Direction

Drainage calculation

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 (Figure 31), sink areas and visualize the most probable stream network
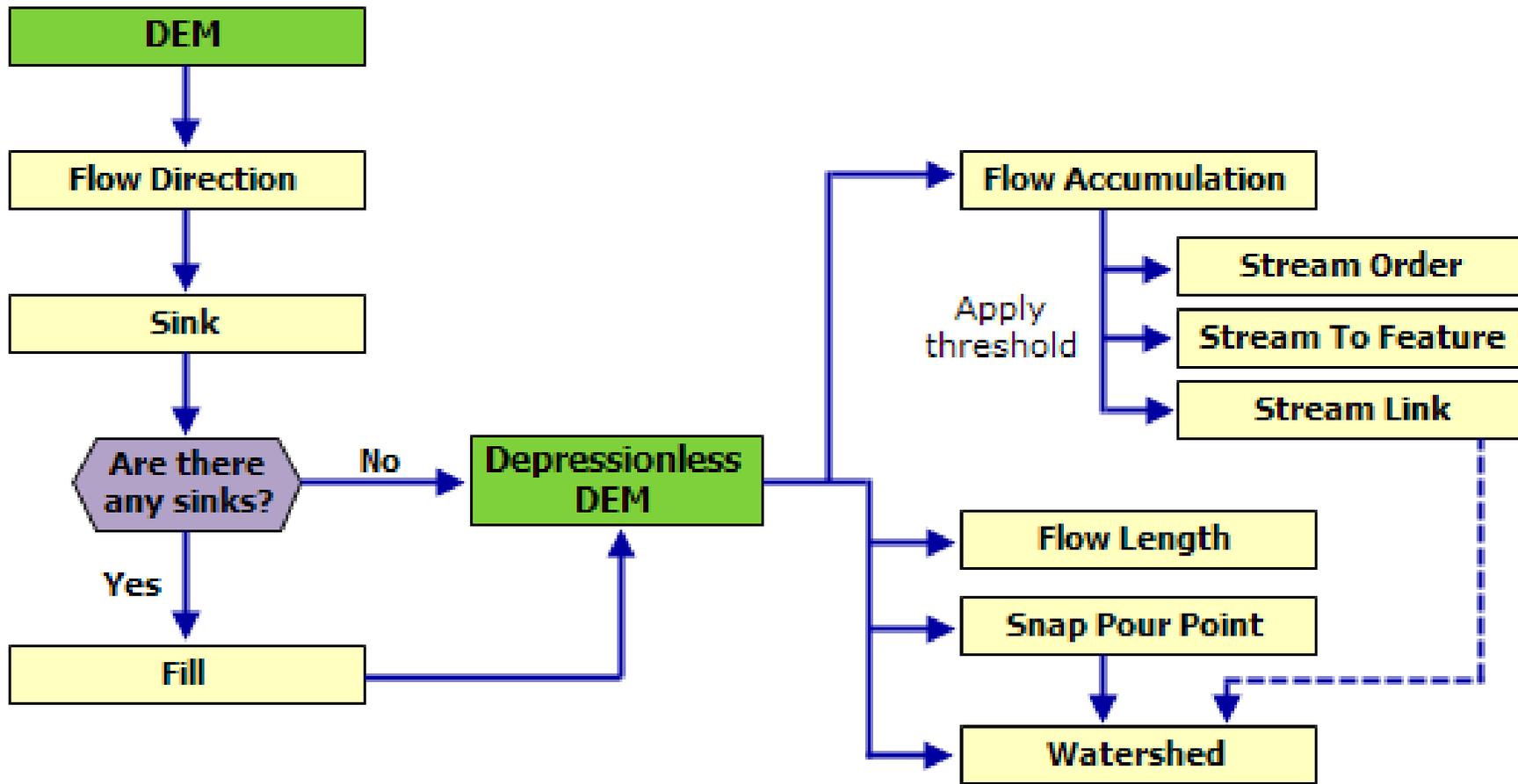
Hydrological modelling (Curtesy of ESRI ArcMap tools)

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 tried to derive runoff characteristics.

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

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

Shade calculations

Shadow casts 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 (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.

Insolation Map of Study area

Solar Radiation

Wh/Sq m

High : 1,45898e+006

Low : 8,50069
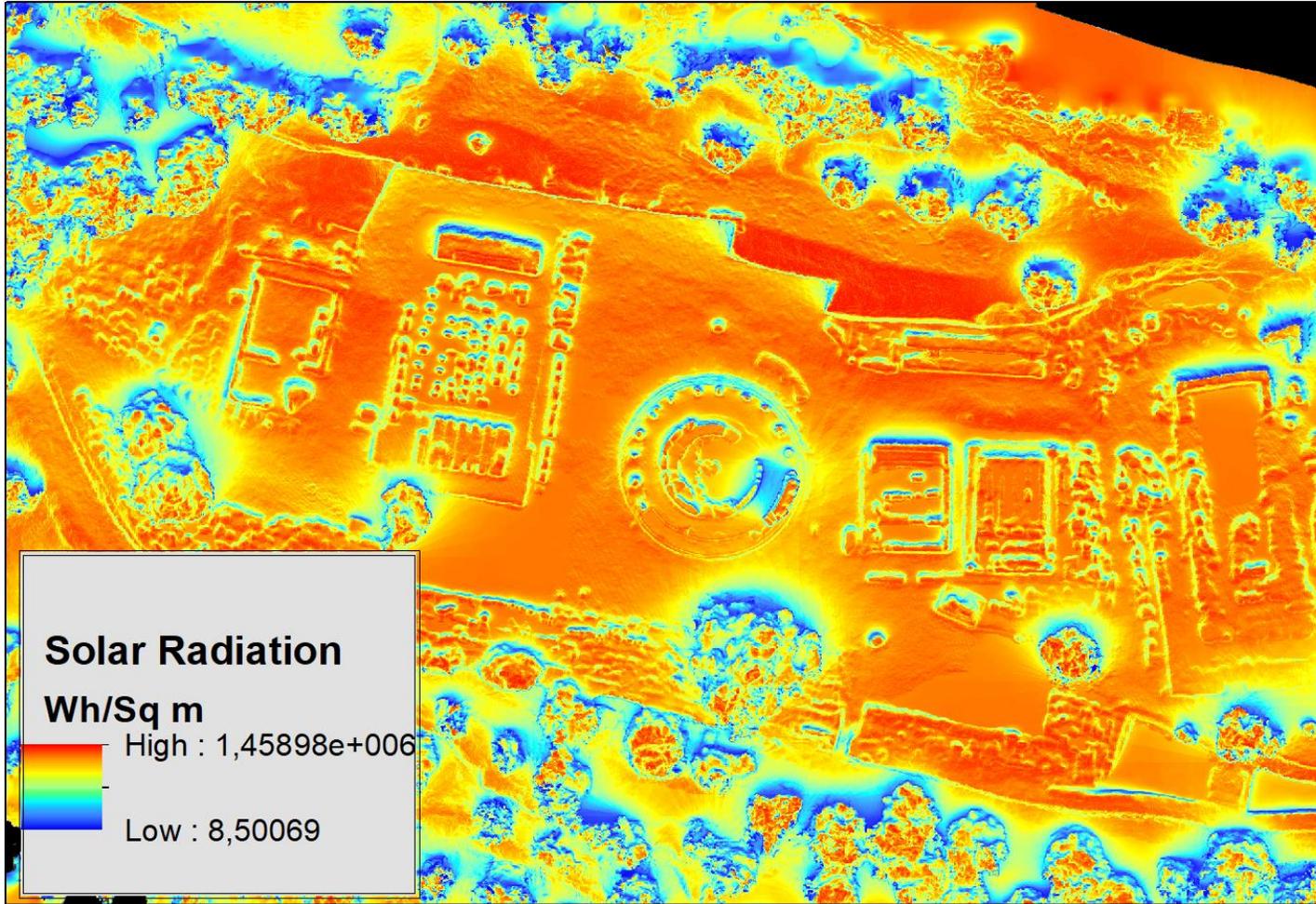
1. Total solar radiation

Solar radiation: (a) can affect the aging of monuments especially in conjunction with restoration/conservation treatments like laser cleaning. (b) is directly connected with vegetation growth as part of landscape architecture and maintenance as well as part of fracture filling

- 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, to calculate the insolation across site given per year, producing insolation map.
- Points Solar Radiation tool, to calculate the amount of radiant energy for a critical antiquities per year with month intervals.
- In this Figure 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.
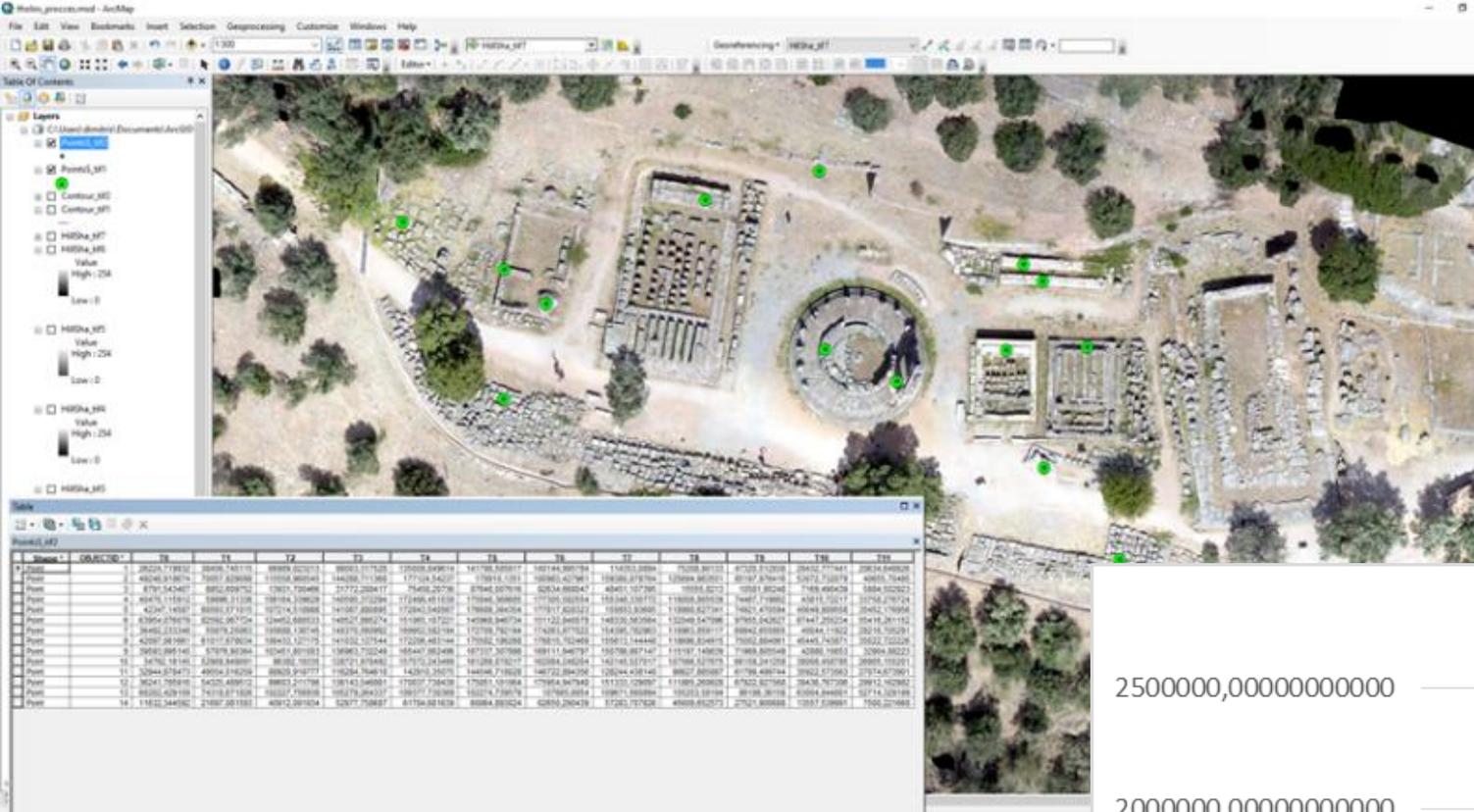
Selected Points and calculated solar radiation intervals, stored as attributes. Graphed values testify the difference of irradiance within the year

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
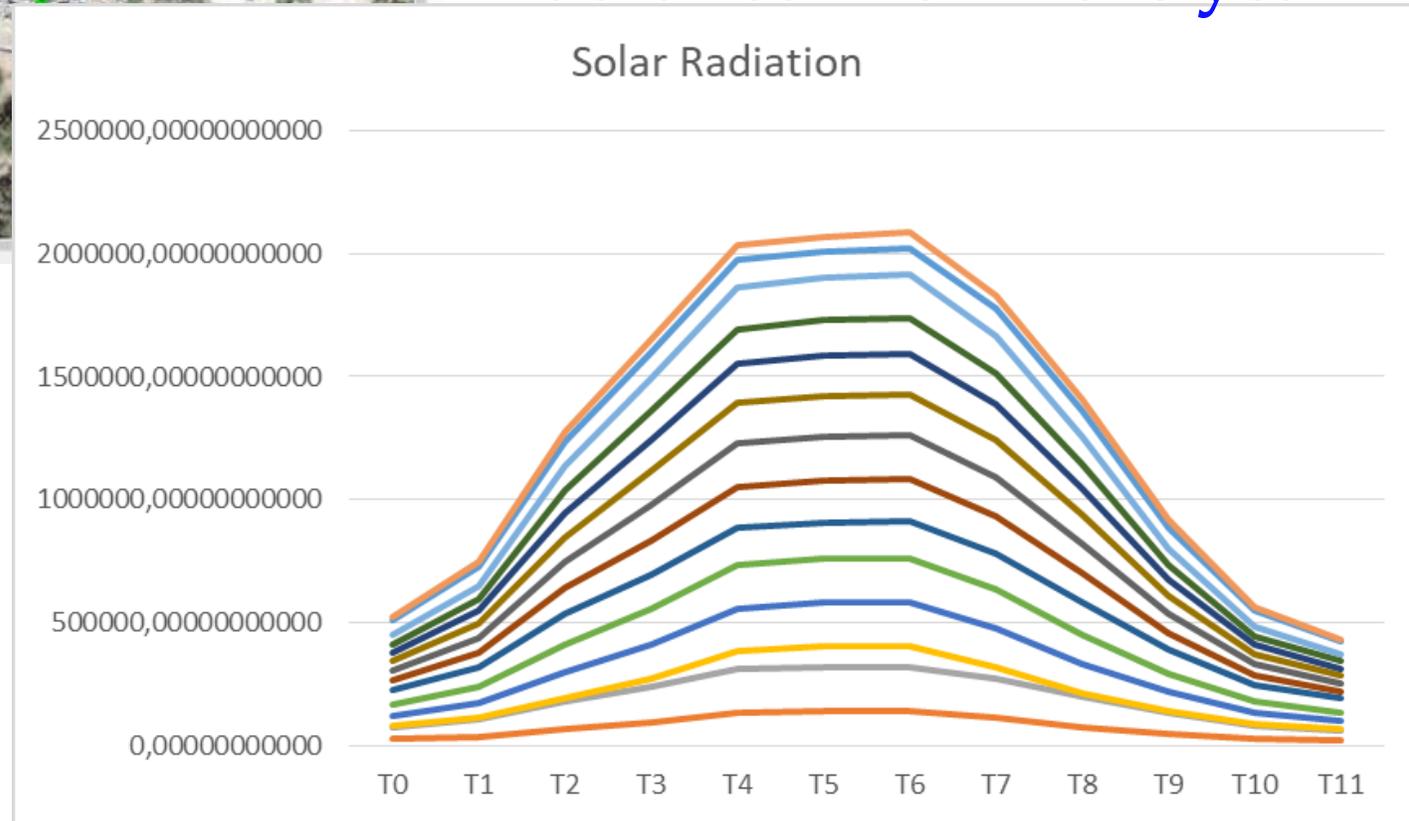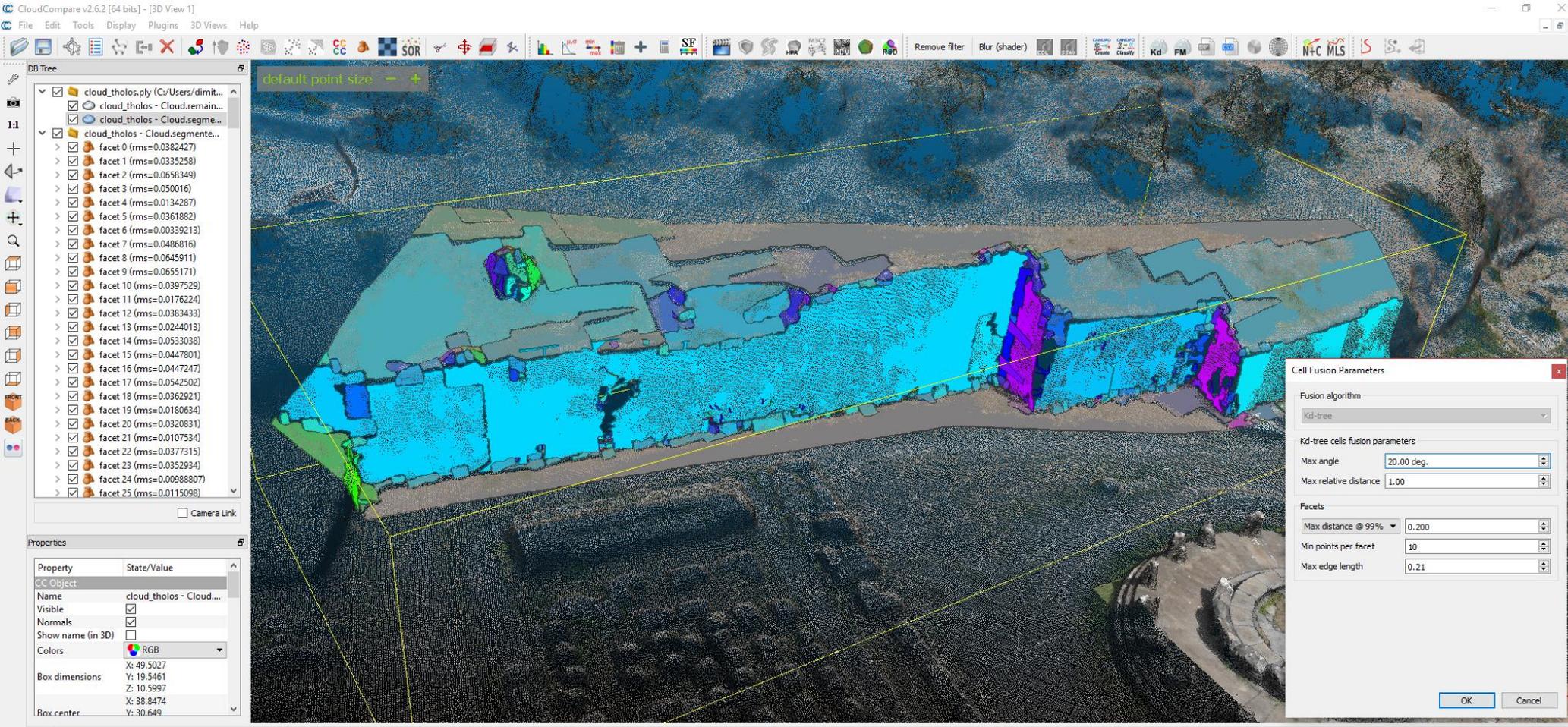
Calculated facets and Cell Fusion Parameters used in Cloud Compare software

1. 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**. For further analysis with the Facets it was used a **plugin created and financed by Thomas Dewez, BRGM to Extract planar facets with a kd-tree** https://hal-brgm.archives-ouvertes.fr/hal-01333950/document.

dip direction: 0°

270°

90°

180°
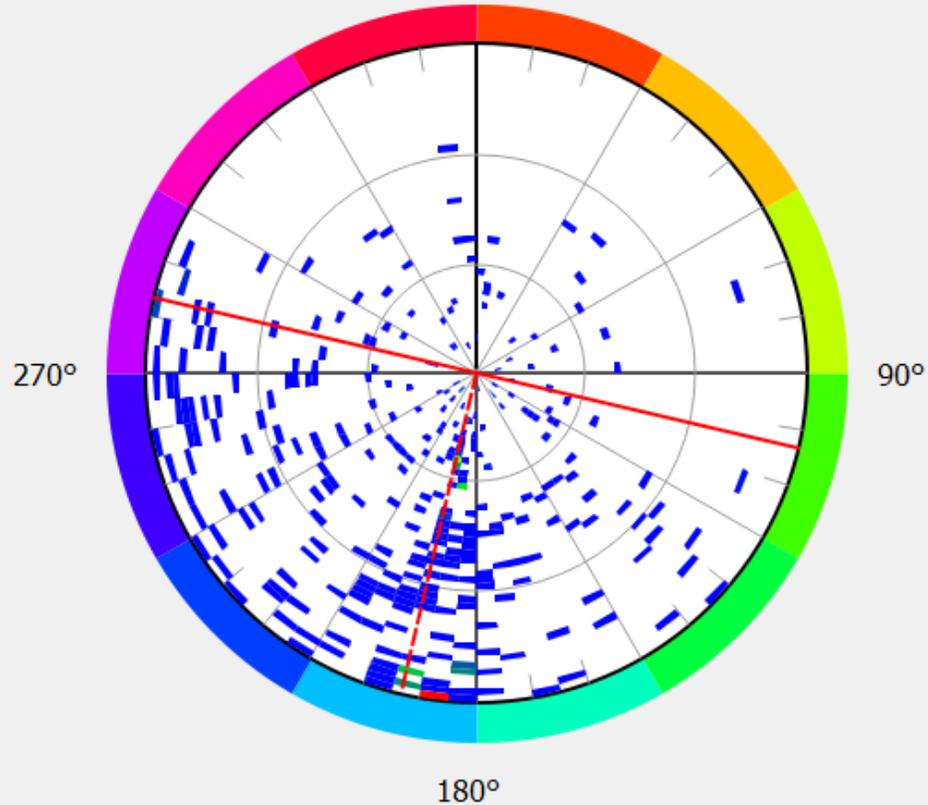
[Mean] Dip direction: 193 deg. - Dip angle: 040 deg.

Stereogram of Facet orientations
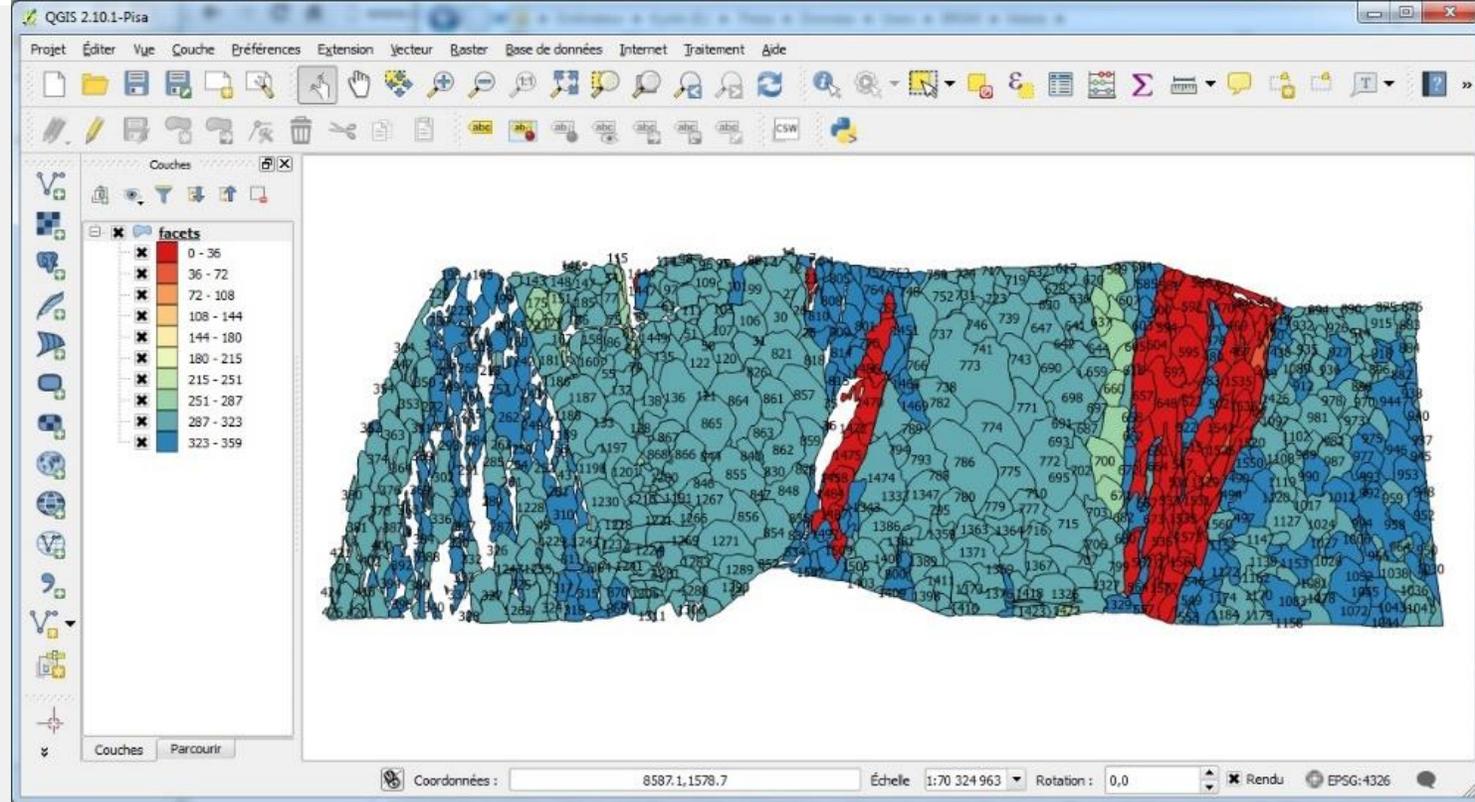
Facet shape File, imported to GIS Software (QGIS 2.1) Curtesy of CloudCompare.org

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

The resulting shape file will be composed of 2D polygons. 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

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

- It is 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.

- For this purpose we used digitized information of the study area, adding 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 between monument's azimuth and age, though azimuth is also related to celebrating deity too at a particular date in the year.
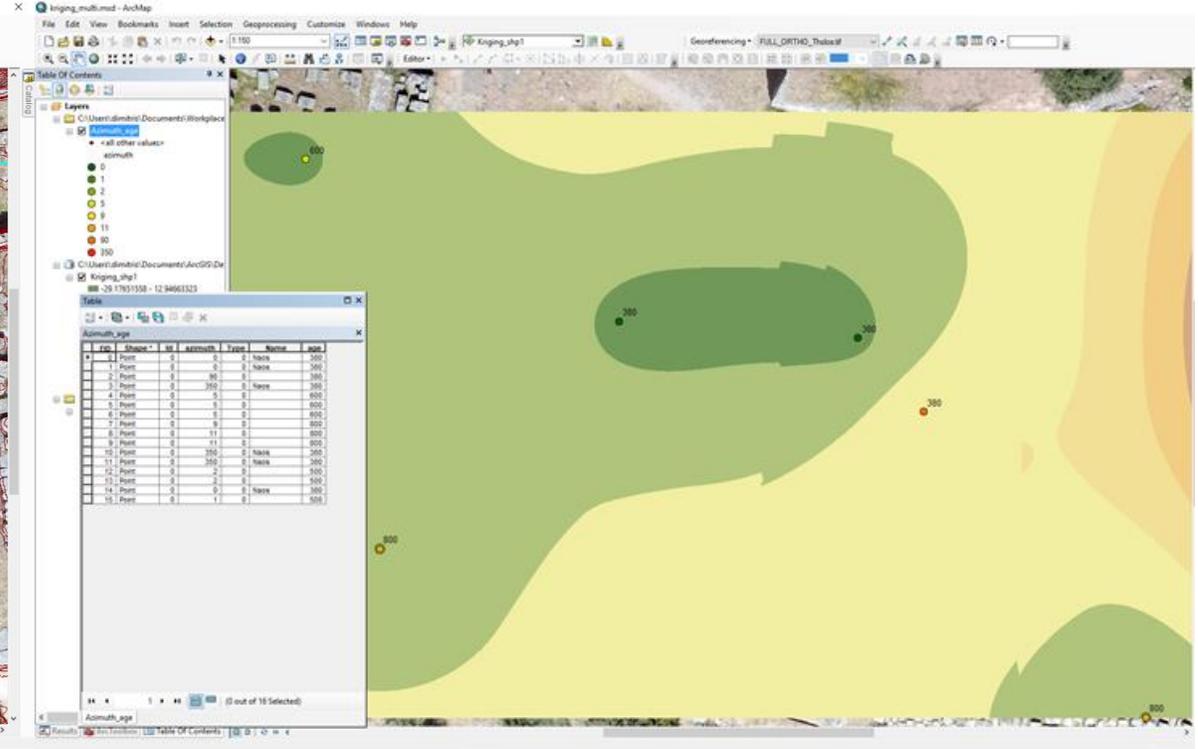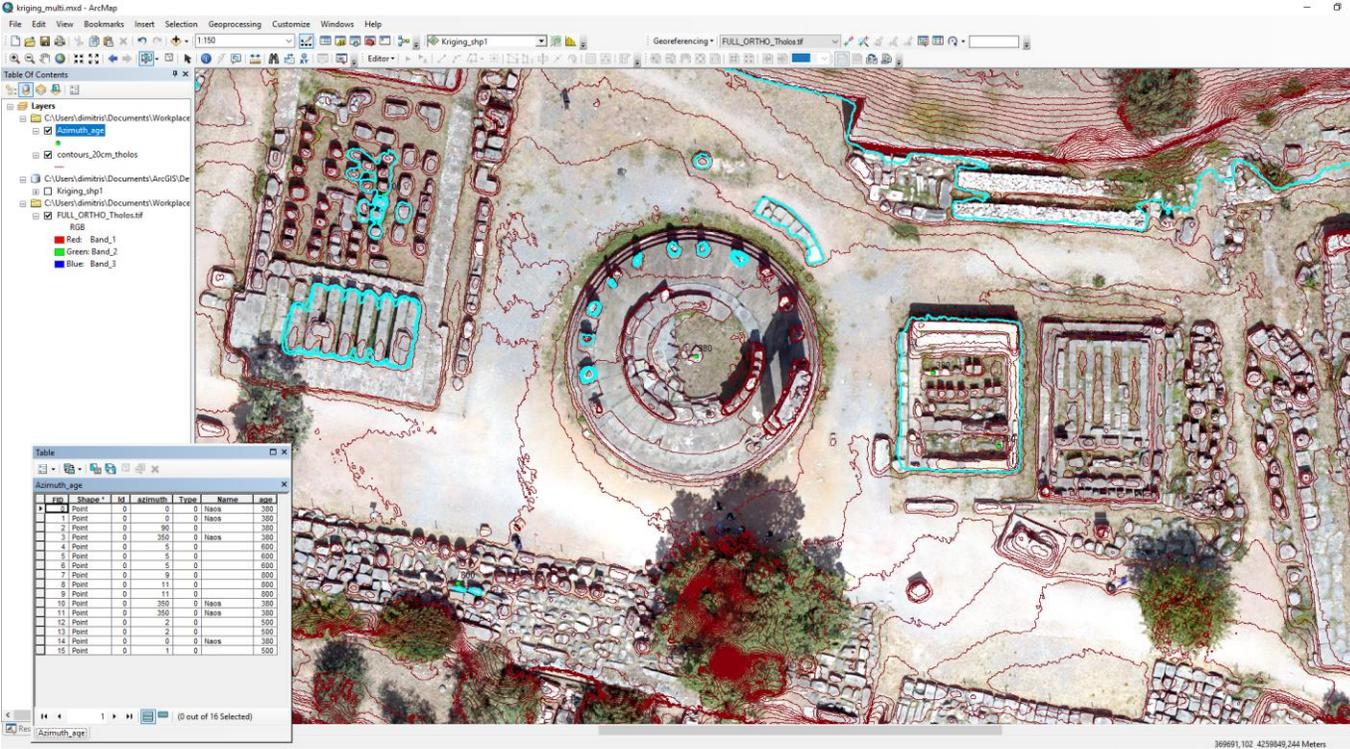
Digitized artifacts and attribute table containing Azimuth and Age information in ArcMap GIS Software

Calculated Surface model of Azimuth measurements and the numbers 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. 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. From secondFigure, 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.

Table

Azimuth_age

FID	Shape *	Id	azimuth	Type	Name	age
0	Point	0	0	0	Naos	380
1	Point	0	0	0	Naos	380
2	Point	0	90	0		380
3	Point	0	350	0	Naos	380
4	Point	0	5	0		600
5	Point	0	5	0		600
6	Point	0	5	0		600
7	Point	0	9	0		800
8	Point	0	11	0		800
9	Point	0	11	0		800
10	Point	0	350	0	Naos	380
11	Point	0	350	0	Naos	380
12	Point	0	2	0		500
13	Point	0	2	0		500
14	Point	0	0	0	Naos	380
15	Point	0	1	0		500

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.

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.

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.

3D models of the monument Tholos made by SfM
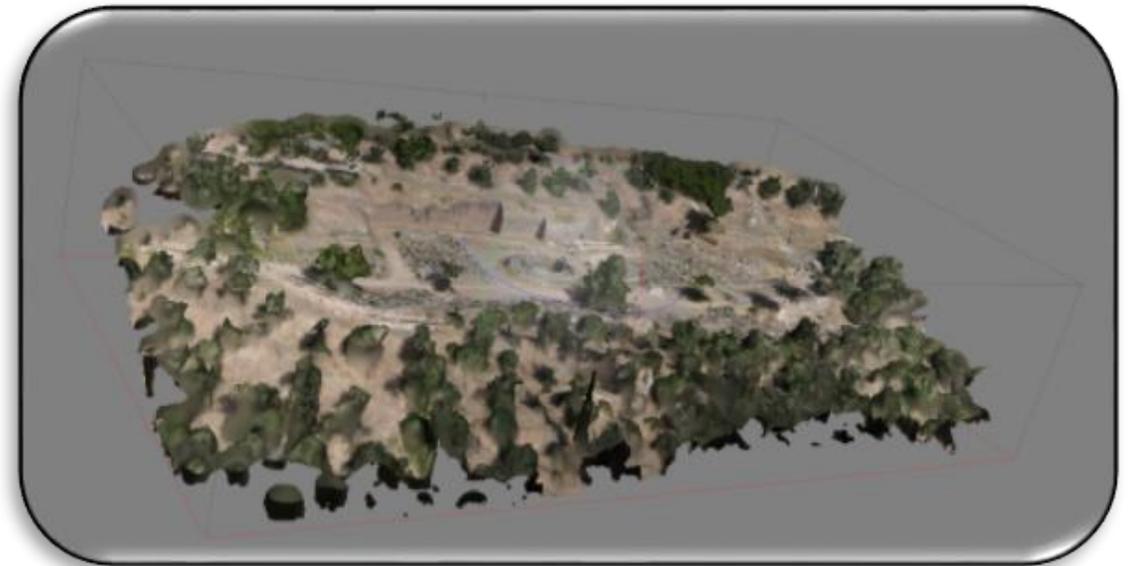
EDUCATIONAL PRODUCTS FOR GAME ENGINES

- 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 previous Figure, 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.

- For example, Unity3D game engine software, 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.

- 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.
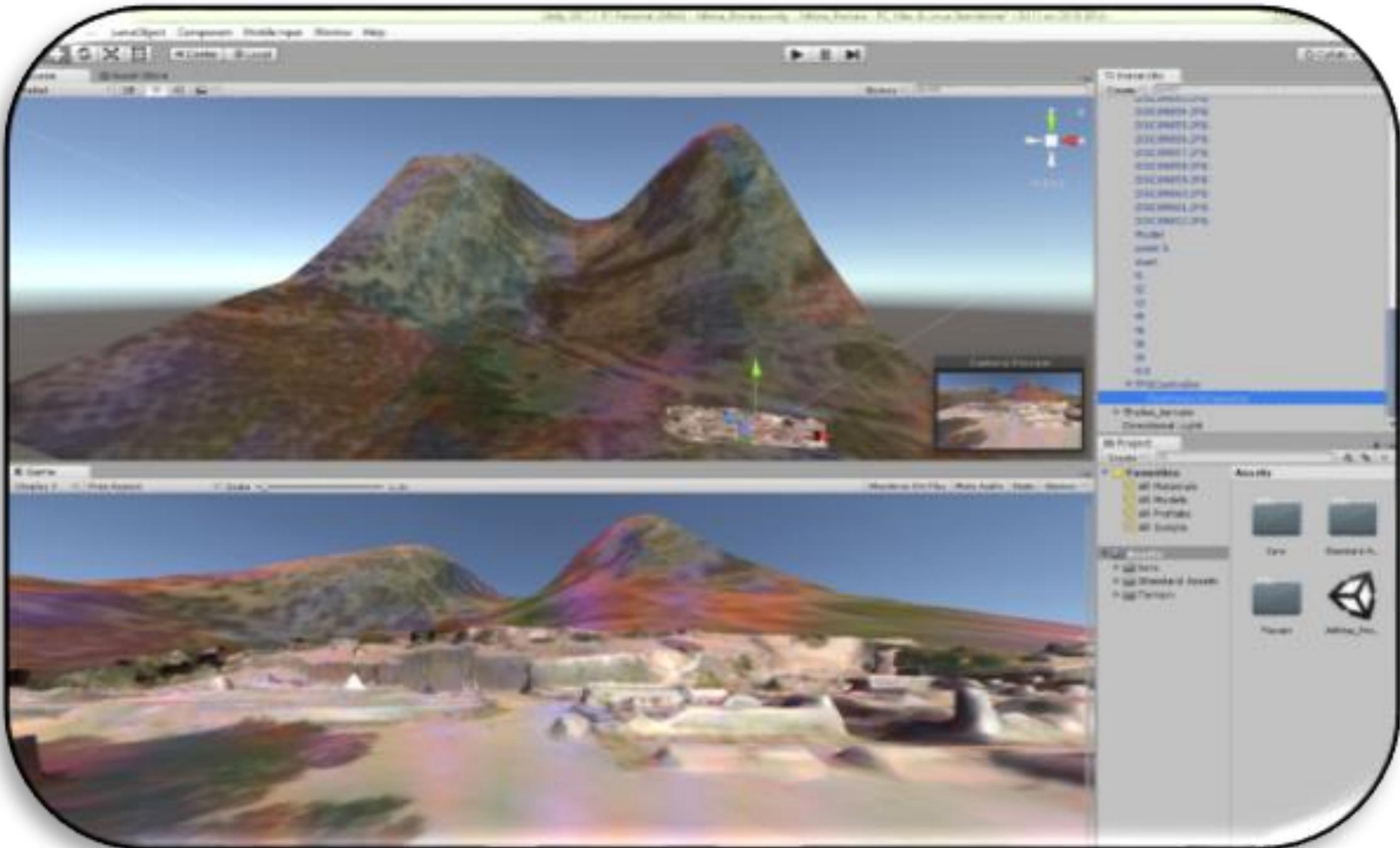
3D models inside Unity3D

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 interdisciplinary nature of such projects is essential and necessary as well as the communication between all the experts.

- 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.

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ACKNOWLEDGEMENTS

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Education

- Most educators give emphasis on learning process and pay little or no attention to the right use of knowledge.

- Therefore, Education means clear definition of wrong and right.

- Aristotle in his book "The Nikomachaean Ethics, B-6, B-7" defines the right and wrong limits as a midway of virtue and if someone is performing inside this midway is doing right while if performing outside is doing wrong.

- This midway region is, according to Aristotle, located between two extreme locations vices or badness, the one being towards a sub estimation (*deficiency*) of virtue and the other towards an over estimation (excess) of virtue.

- Therefore, concerning virtue, we can adopt as significant human error the outside of these limits human actions either they are in excess, or they are deficient to conform to virtue midway limits.

- Aristotle's example about courage is illustrating this definition of human error stating that "*in midway between a coward and a provocative is the virtuous one (correct one) of courage*". Accordingly we may say that "*in midway between a stingy and an overspending person is the virtuous one (correct one) of thrifty*".

- Aristotle is also stating that the *effort* to maintain actions within the midway of virtue is the characteristic of a virtuous person, who is learning from mistakes and is trying to minimize them. Aristotle's midway of virtue is actually a basic step towards modeling of human error

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Absolute correct human mind state as defined by Plato:
logic balances exactly desire and anger
Acceptable correct human mind state as defined by the Aristotle:
logic balances desire and anger within midway of virtue

$$L_B{}^2 = D^2 + A^2 + D.A. \cos(\theta)$$
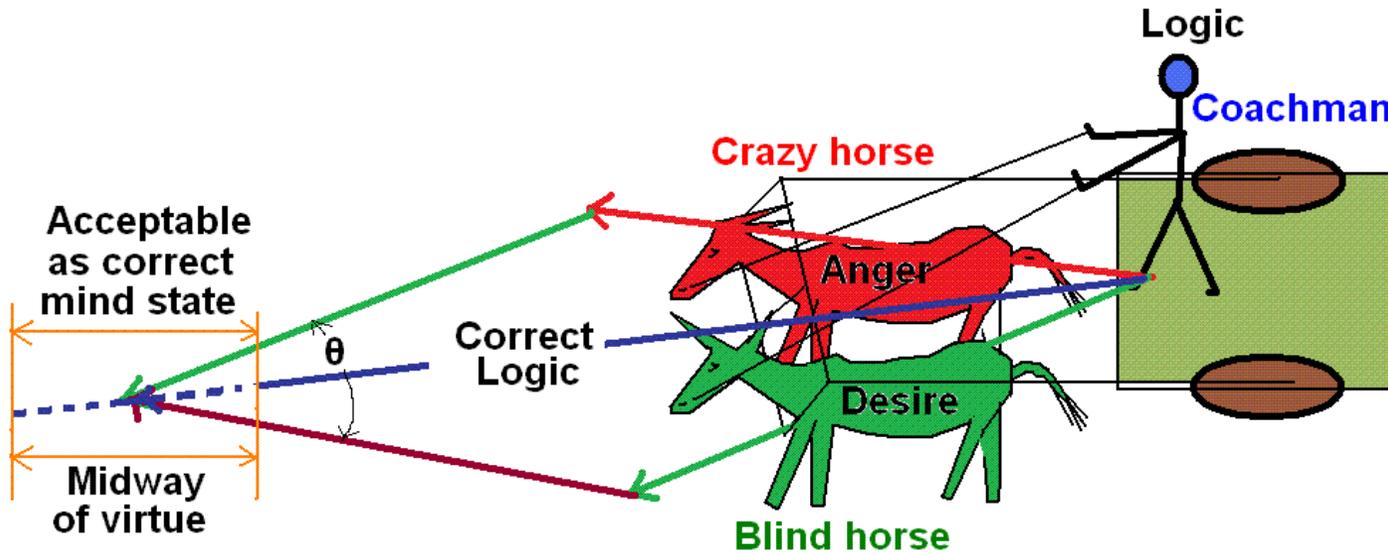
$$L_B{}^2 = D^2 + A^2$$
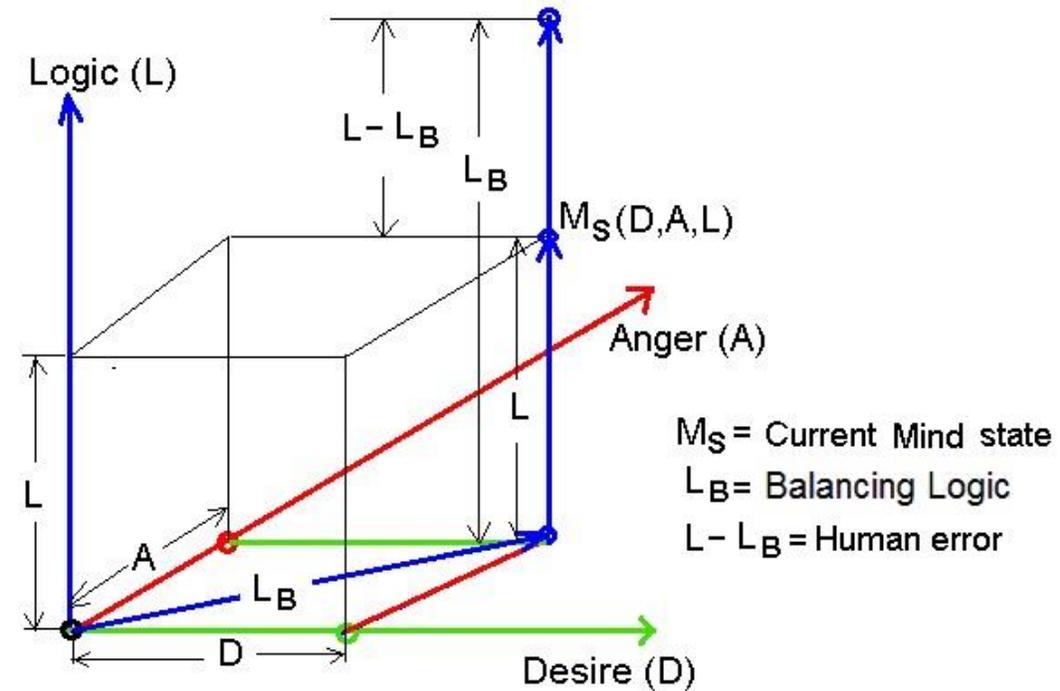
Mother of all scientific fields is philosophy, which comprises all scientific fields.

http://www2.env.aegean.gr/labs/Remote_sensing/EnglishBlock/publications/Education-Neural-Net-Systems-Hatzopoulos-Public.pdf

THANK YOU