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3D Modelling of Petrified Trees: Laser Scanning vs Photogrammetry

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Abstract **– In this paper, a methodology for the photogrammetric and laser scan survey of tree fossils of the Petrified Forest on Lesvos island in Greece, is proposed.The Petrified Forest is of particular interest since it is one of the rarest monuments of geological heritage worldwide and it was formed from the fossilized remains of plants. During this study, photogrammetric and laser scanning data by the tree fossils have been gathered, processed and modelled in 3D, and a comparison of the two techniques is taking place. Finally, the most suitable technique for the 3D modelling of objects such as the petrified trees is proposed.**

I. INTRODUCTION

Laser scanning and image-based modelling techniques became very popular the last few years for the 3D modelling and continuous monitoring of historical objects [1]. Laser scanners have turned out to be progressively productive as far as point acquisition speed, user-friendly, portability and cost. New improvements can also be featured about close-range photogrammetry because of the presentation of new algorithms and software. The tree fossils are significant heritage objects, and the Petrified Forest constitutes a part of the cultural identity of Lesvos Island. The data used here were obtained from our experimental 3D measurements of one petrified tree trunk and one radical tree system. The data have been collected inside the Natural History Museum of the Lesvos Petrified Forest. We have conducted this field experiment to investigate the feasibility of terrestrial photogrammetry and terrestrial laser scanning.

II. RELATED WORK

The advent of range-based and image-based technologies for modelling has led to many publications where comparisons between the two techniques were presented [2, 3], and especially for cultural heritage objects [4, 5, 6] but never for petrified trees. Laser scanning and photogrammetry are two techniques with some common attributes such as:

- Depending on the complexity of the surveyed objects, they can give a complete 3D virtual model, which is intended for documentation and visualization in short time.
- They make use of equipment that is relatively easy to collect the data with, as well as easy to use when referring to the programming part and also performing 3D measurements.

III. STUDY AREA

Lesvos Island is located in the Northeast part of the Aegean Sea in Greece.The Petrified Forest of Lesvos covers an area of 15,000 hectares. It has been classified as a natural monument of global value and is one of the finest testaments of the evolution of plants during Miocene. The Petrified Forest of Lesvos was formed around 18,5-17,0 million years ago due to the intense volcanic activity which buried the forest under thick layers of volcanic ash and pyroclastic materials. The plant fragments that created the famed “Petrified Forest” are found throughout the western part of Lesvos, with the most important concentrations being in the areas of Sigri, Eressos and Antissa.

The earliest references to the Lesvos Petrified Forest dates back to the 19th century. Since then, it has aroused the interest of many travellers and scholars. Scientists who studied the Petrified Forest refer to its uniqueness and its great scientific value as a complete forest ecosystem fossilized in situ and preserved in excellent condition until the present day. A systematic study of the petrified tree trunks and leaves determined the genus and species of the Petrified Forest of Lesvos plants [7, 8, 9].

More specifically, petrified trunks of conifers and angiosperm trees have been identified. Many trunks belong to the Taxodiaceae family, the ancestral form of the modern day sequoia and also the Protopinaceae family, the ancestral form of the modern day pine. Representatives species of poplar, laurel, cinnamon tree, plane tree, oak, beech, alder, maple and cypress were also identified. The synthesis of the petrified flore indicates that the Lesvos Petrified Forest was developed in a subtropical climate. The high frequency of the petrified trunks preserved upright with their root systems in full development certifies that the trees were petrified in their natural position and had not been moved to the position we find in today [9]. It is, therefore, an autochthonous petrified forest. Impressive upright and downed tree trunks that reach a length of up to twenty meters and a diameter approaching three meters were revealed by the natural erosion of the volcanic formations[9, 10].

In recent years, discoveries come to light by the systematic excavations carried out by the Natural History Museum of the Lesvos Petrified Forest (Fig. 1)[11]. In 1985 was declared a protected natural monument and since 2000 it is included in the Lesvos UNESCO Global Geopark.

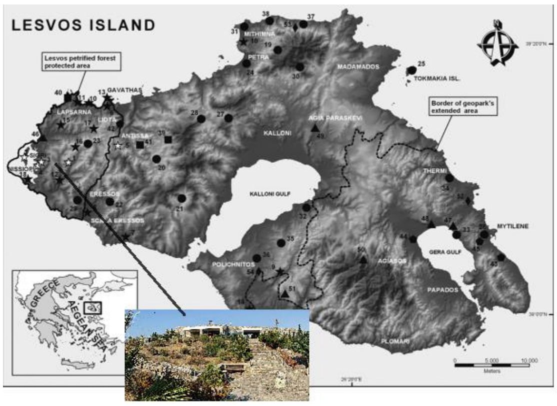

Fig. 1. Study area [11]

The Natural History Museum of the Lesvos Petrified Forest, studies, researches, maintains and protects the Petrified Forest for the last 23 years.

As we have already mentioned, the data used here were obtained from our experimental 3D measurements of a petrified tree trunk and a radical tree system. This characteristic white tree trunk (Fig.2) was lying at the bottom of the sea at the eastern coast of Nissiopi islet, at the bay of Sigri. This very well-preserved internal structure made possible the identification of the tree as an ancestor of today's Sequoia (species Taxiodioxylon-gypsaceum). Pyroclastic material covered the trunk and silicified during lower Miocene. It was revealed as a result of the natural erosion of the volcanic rocks and during Quaternary was covered by the uplift of the sea level. The tree trunk is 3 meters high with 0.60 meters diameter.

Fig.2. Study area 1, tree trunk

The radical tree system (Fig. 3) is one of the most characteristic petrified trunks in the Petrified Forest Park of Sigri and was discovered in its original position[10, 11]. This is a conifer of the Protopinaceae family, and it is characterized by well-preserved bark, internal structure and root system. The trunk is 0.60 meters high and has a circumference of 2.70 meters. In the trunk's interior structure there are impressive large growth rings. Also at the base of the trunk, there is a root system with nine branches in full development attesting to the fact that the Petrified Forest of Lesvos is autochthonous, meaning that the trees were located in the same position before petrification [8, 10]. The autochthonous nature of the forest renders this petrified monument truly unique [10, 11].

Fig.3. Study area2,radical tree system

IV. METHODOLOGY

In our proposed methodology (Fig.4) the first step is to plan the metric survey. We chose a petrified tree trunk and a root system for the implementation of the two techniques, photogrammetry and laser scanning. The data has been collected using a 3D laser scanner (Faro Focus^{3D}) and a 20-megapixel digital camera (Sony A5000). The constraints of the two techniques were taken into consideration, and multiple scans and many photos were necessary for the 3D modelling of the tree fossils.

The next step of the methodology is the positioning of targets and control points and at the same time the decision about where the stations of the laser scanner would be. At this point, the research for the best areas where the targets would be placed was carried out. The targets were placed in areas that would serve both data collection methods. The raw data consist of a dense point cloud. Multiple scans are needed most times, so the whole object should be covered. Then, the individual point clouds must be registered to the same coordinate system. All point clouds were planned to be registeredby using three reference spheres as well as a number of checkerboard targets, two targets for the tree trunk and eight targets for the radical root system. Control points were used for the quality assurance of the final 3D models.

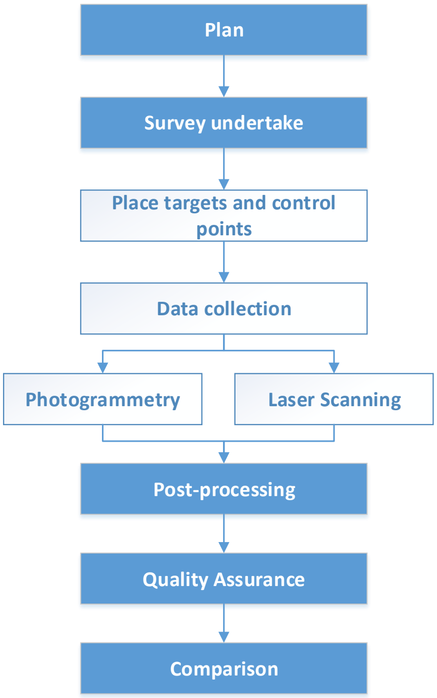

Fig.4. Plan of the proposed methodology

a. <u>Laser Scanning</u>

Laser Scanning is an active sensor approach, able to recover directly 3D measurements of the scanned scenes which can be combined with color digital images. The fossils were surveyed by a phase-based Faro Focus^{3D} terrestrial laser scanner.

One of the most important considerations in the field scan is the selection of the scan position and the number of individual scans needed. In this study, the scanner was set up at eight stations around the radical tree system and nine stations around the tree trunk in consideration of various factors such as overlap and measurable range (Fig.5). The scan range was 0^o to 130^o range horizontally and -30^o to 30^o range vertically. The selected resolution was at 1/2 on the Focus^{3D} laser scanner. That resolution records a point every 3mm at a distance of 10m. The selected quality was 2x, which means that every point was fired two times by the laser scanner for more accurate z-value. With this step, the plannning of the research was completed, and we went through the collection of data.

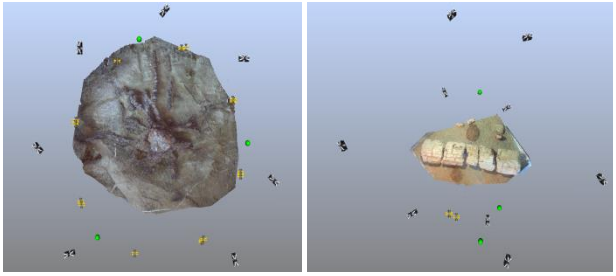

Fig. 5. Laser scanning observation plan

The post-process phase of the scanned data was completed using the Faro Scene software (particularly designed for all Focus laser scanners where users can process, register and examine scan data profic-iently).Thus, the Scene software has been used for the registration of the collected data and the calculation of the mean and the standard deviation values for each object where the scans were joined into a single point cloud.All the statistics of the model's registration are illustrated in Table 1.

Table 1. Scans Statistics

Target Tensions	**Tree trunk**	**Radical root system**
Mean:	0,0016	0,0023
Deviation:	0,0022	0,002
Min:	0,0000	0
Max:	0,0131	0,009

b. Photogrammetry

Photogrammetry obtains reliable measurements, and the results of the photogrammetric process are a point cloud of thousands of surface points for each footprint. These point clouds are then connected to form entire surfaces.

The digital images of the fossils were acquired by a Sony A5000digital camera. The shooting distance varied from 20cm to 50cm depending on the objects, which have been taken parallel rotated and oblique. A set of 200 images per study object was acquired through a fixed focal length (16mm), with 0.00440081 pixel size. The resolution was 5456x3632. The quality of the 3D model depends on the photos. For this case, we take into consideration few things that we propose through this study. Initially, we need to use a tripod in our camera to ensure the best stability and quality of the photos. Next, it is considered necessary to check the weather conditions as well as the duration of the photo shooting. Additionally, it is critical to maintain a strategic distance from any shadows since issues will emerge during the processing and the creation of the 3D model. At that point, we set our camera, since for our experiment it is pivotal to have clear, colorful images. The ISO must be 100-200, as it is important to have low sensitivity to light and the finest grain. If the ISO is so low then it is possible to shoot at higher shutter speeds and/or smaller apertures. In order to block the light around our object, the size of the aperture must be f/8 to f/9. To ensure one good and clear 3D model the quality of the pictures has to be more than 0.7 (Fig.6). The Agisoft Photoscan software has been usedin order to create a 3D model (a user-friendly software for business and research purposes).

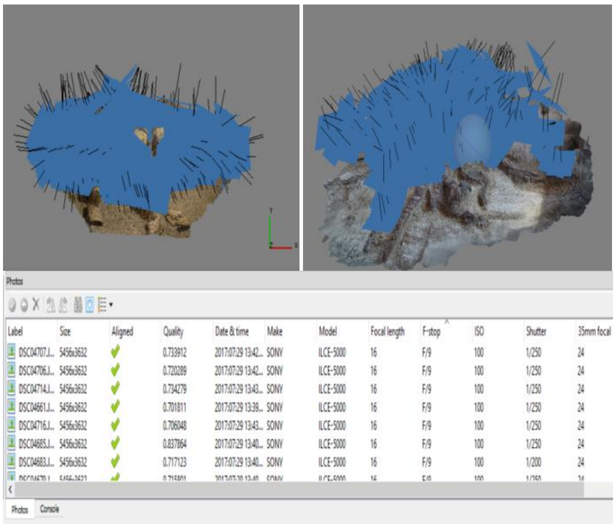

Fig. 6. Photography positions and details of the images

Initially, image processing involved the arrangement of the photographs, followed by the extraction of the point clouds. All the details of the two photogrammetric models are shown in Table 2.

The last step of our survey plan is a comparison between the results of the survey objects as well as the results achieved by photogrammetric and laser scanning techniques. To compare the two models, the open source Cloudcompare software was used (a 3D point cloud processing software which can handle triangular meshes and calibrated images).

The two photogrammetric models have been cleaned off from the noise although perfect consistency with noise removal was impossible. For one more time, we have to underline how crucial is to indicate few control points in order to improve the geometry and to reference the final models. The photogrammetric point clouds are aligned to those acquired by the laser scanning process, using the Iterative Closet Point (ICP) alignment tool. The point clouds created by laserscanner and photogrammetry are not georeferenced, but using the tool “match scales” of Cloud compare they can be aligned at the same scale. Then with the “translate/rotate” tool the best fit between the two clouds was achieved.

Table 2. Photogrammetry Processing summaries

	Tree trunk	Radical root system
Property	**Value**	**Value**
General		
Cameras	182	283
Aligned cameras	182	283
Markers	4	4
Scale bars	2	2
Point Cloud		
Points	176,357	205,178
error	(1.64511	(1,92623 pix)
error	.8429 pix)	99 pix)
size	6.1251 pix	6,92923 pix
Effective overlap	433.412	727.967
Alignment parameters		
Accuracy	Medium	Medium
Pair preselection	Generic	Generic
Key point limit	40,000	40,000
Tie point limit	4,000	4,000
Constrain by mask	No	No
Optimization parameters	cy, k1-k4, p1,	f, b1, b2, cx, cy, k1-k4, p1,
Dense point cloud		
Points	1,308,588	16,940,560
Reconstruction		
Quality	Medium	Medium
Depth filtering	Aggressive	Aggressive
Model		
Faces	29,194	25,315
Vertices	14,765	12,806
Texture	4,096	4,096 x 4,096
Reconstruction		
Surface type	Arbitrary	Arbitrary
Source data	Sparse	Sparse
Texture parameters		
Mapping mode	Generic	Generic
Blending mode	Mosaic	Mosaic
Texture size	4,096 x 4,096	4,096 x 4,096

V. RESULTS AND DISCUSSION

The results showed that we could take reliable measurements with both techniques. The 3D model of the tree trunk made by the photogrammetry survey is shown in Fig. 7, while the 3D model of the root system made by laser scanning survey is shown in Fig.8. It is necessary to mention that the final 3D model of the root system in Fig. 8 consists of eight individual scans (to eliminate shadows) that are registered together.

Fig.7. Tree trunk 3D model by photogrammetry

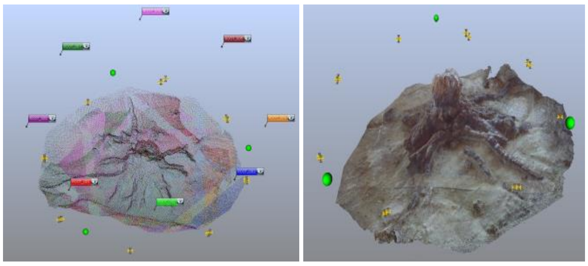

Fig. 8. Root system 3D model by laser scanning (left: multiple scans positioning)

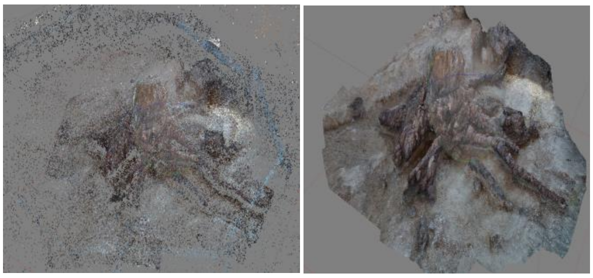

Fig.9. Root system 3D model by photogrammetry

The proposed approach can be used not only for 3D modelling of tree fossils but also in other similar heritage objects.

Fig.10. Visual comparison between the Photogrammetric model (right) and the colored scanner point cloud (left) of the radical root system

It is interesting to point out that the difference between the laser and the photogrammetric model is visible allowing to distinguish every detail of the trunk and the roots on both models.

The comparison results of the two methods by Cloudcompareare shown in the figures 11 and 12. Comparing the two objects, namely the tree trunk and the root system and with the help of the scale next to the models we conclude that at the root system there is a better fit of the two techniques than at the tree trunk. The referenced model at both cases was the 3D model by the laser scanner and the aligned model was the 3D model by photogrammetry.

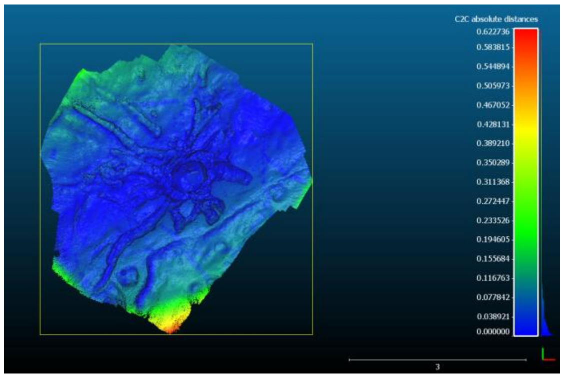

Fig 11. The radical tree system after the merge of the two point clouds

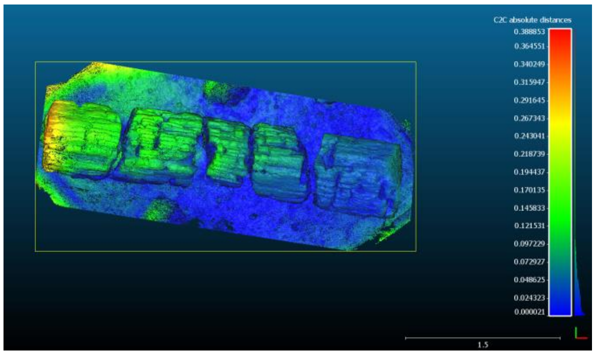

Fig. 12. The tree trunk after the merge of the two point clouds

VI. CONCLUSIONS

The 3D modelling of a petrified tree trunk and a root system using photogrammetry and laser scanner techniques are being covered in this paper. The inspection of the results revealed that both the photogrammetric survey and the laser scanning were successful and provided reliable data. The outcomes by the two methods represented excellent quality and precise 3D models. However, through this study, we would like to emphasize that there are many variables in terrestrial laser scanning and in photogrammetry to be taken into consideration such as:

- good knowledge of photogrammetry
- a good camera and equipment
- user-friendly software
- control points and targetsare unquestionably recommended
- practise and experience are necessary for higher accuracy models.

More specifically, in the case of the root system, photogrammetry recovered an accurate 3D model, despite the fact that in few sections, the light conditions were poor. Also in few parts the images did not cover exceptionally well the lower parts close to the ground. Of course, this can change by taking more photos of these areas. In general, as we have already mentioned above in the presented examples, the photogrammetry gave accurate outcomes with no external intervention. Additionally, this is also a low-cost technique and produces, accurate models of the trunks despite their complexity.

On the other hand, in order to export high-resolution models, the procedure can be extremely time-consuming, as the image matching software is considerably more time-consuming and requires a powerful computer. In our case just the alignment of the photos of the tree trunk, took almost eight hours, while the overall photo-grammetric processing time was approximately eighteen hours. Another problem with photogrammetry is the existence of few gaps in the model of the tree trunk, especially in deep fractures, although photos are showing these areas and the reconstruction is accurate. So, may the algorithms used by AgisoftPhoto scan request a greater certainty in the dense image matching and cannot execute the model properly with these images that have a lower quality.

Regarding all of this time consumption, the laser scanning is the best technology becauseit provides full resolution scans in real time. The 3D model obtained from the laser scanner with the use of targets spheres guarantees a better result and in much less time. In general, in both methods, an issue that can arise is the existence of the shadows that we could not keep away from, and they made numerous challenges during the processing. Parallel rotated photographs caused problems on scale differences, so greater consideration during the photo shooting is required.

The proposed strategy can be clearly viewed as a fully autonomous system. The human intercession is required only to scale the final model. The main advantage is that it works with low-quality images, different scale and illumination and poor texture as in few parts of our objects.

Throughout this entire study and the difficulties we had to face, there are some notes worth mentioning that guarantee correct camera alignment. Too many photos make the procedure extremely slow. On the other hand, a low number of photos could convey to a poor geometry and absence of information. The photos ought to have close base capture distance especially in corners or difficult areas (in our case that we had 360° degrees objects we had to take photosin every 4° degrees).

ACKNOWLEDGMENTS

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