

## PHOTOGRAMMETRIC DOCUMENTATION AND DIGITAL REPRESENTATION OF EXCAVATIONS AT KEROS ISLAND IN THE CYCLADES

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### ABSTRACT:

Within the framework of excavations at Keros Island in the Cyclades, the focus of this study is targeted mainly towards the use of UAV (unmanned aerial vehicle) for the production of high resolution orthoimages, essential for the interpretation, detection and measurement of archaeological features and the use of laser scanner for the 3D documentation of archaeological trenches, dtm collection of the whole archeological site, Kavos and Dhaskalio, and 3D modelling of Cycladic figurines.

For the acquisition of the aerial images in the site of Kavos and Dhaskalio, a flight planning prior to fieldwork and a careful acquisition of the images was required to ensure successful post processing. The photogrammetric image processing of the data, comprising of the tie point measurement, bundle adjustment, dsm and orthophoto generation was completed and the resulting accuracy was acceptable for the 1:500 mapping. A flythrough video was created also using the produced orthophotos and a Quick Bird Image in order to place the archeological site among a wider context.

For the DTM collection and the modelling of the archaeological trenches an Optech ILRIS-3D laser scanner was used. The trenches were scanned with a 1cm resolution, while the DTM was scanned with a 20 cm resolution. Multiple scans of the objects were realized and they finally merged to produce were photorealistic three-dimensional triangle models. For the figurines modelling a next engine portable scanner was used. The figurines were scanned from multiple angles in order to cover every detail of their surface and were merged to produce high resolution photorealistic 3D models.

## 1. INTRODUCTION

### 1.1 Study area

Keros (Greek: Κέρος) is an uninhabited Greek island (figure 1) in the Cyclades about 10 km (6 mi) southeast of Naxos. Administratively it is part of the community of Koufonisi. It has an area of 15 km<sup>2</sup> (6 sq mi) and its highest point is 432 metres (1,417 ft). It was an important site to the Cycladic civilization that flourished around 2500 BC. Keros is especially noted for the flat-faced marble statues which later inspired the work of Pablo Picasso and Henry Moore.

The Cambridge Keros Project, co-directed by Colin Renfrew and Michael Boyd, conducted excavations in 2006 and 2007 at the site of Kavos (figure 2) on the west coast of the island, where a special deposit of broken choice material has been systematically excavated. This site is believed to be the source of the so-called "Keros Hoard" of fragmentary Cycladic figurines. In 2008, the same project identified a substantial Cycladic period settlement on the nearby island of Dhaskalio, located opposite the special deposit of Kavos.

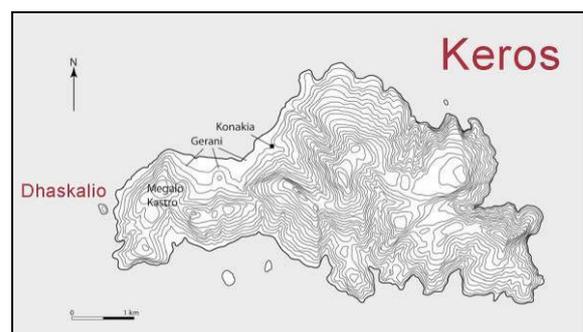


Figure 1: The island of Keros with Dhaskalio at the west.

### 1.2 Scope of the project

Within the framework of excavations at Keros Island in the Cyclades, the focus of this study is targeted mainly towards the use of UAV (unmanned aerial vehicle) for the production of high resolution orthoimages, essential for the interpretation, detection and measurement of archaeological features and the use of laser scanner for the 3D documentation of archaeological

trenches, dtm collection of the whole archeological site, Kavos and Dhaskalio (figure 2), and 3D modelling of Cycladic figurines.

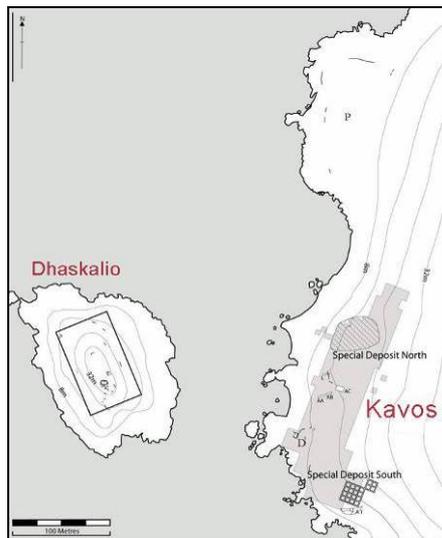


Figure 2: The site of Kavos and Dhaskalio.

For the acquisition of the aerial images in the site of Kavos and Dhaskalio, a flight planning prior to fieldwork and a careful acquisition of the images was required to ensure successful post processing. The images were downloaded and processed already in the field in order to ensure good image quality, sufficient overlap between them and avoid large scale differences as well. The photogrammetric image processing of the data, comprising of the tie point measurement, bundle adjustment, dsm and orthophoto generation was completed and the resulting accuracy was acceptable for the 1:500 mapping. A flythrough video was created also using the produced orthophotos and a Quick Bird Image in order to place the archeological site among a wider context.



Figure 3: Aerial view of Dhaskalio.



Figure 4: Aerial view of Kavos.

For the DTM collection and the modelling of the archaeological trenches an Optech ILRIS-3D laser scanner was used. The trenches were scanned with a 1cm resolution, while the DTM was scanned with a 20 cm resolution. Multiple scans of the objects were realized and they finally merged to produce photorealistic three-dimensional triangle models. For the figurines modelling a next engine portable scanner was used. The figurines were scanned from multiple angles in order to cover every detail of their surface and were merged to produce high resolution photorealistic 3D models.

## 2. AERIAL IMAGE ACQUISITION AND IMAGE PROCESSING

This project phase comprises of the field and processing work, required for the successful photogrammetric documentation of the study area. The photogrammetric documentation consists of the measurement of GCP's using traditional surveying methods, the acquisition of high resolution aerial images with an autonomous UAV (unmanned aerial vehicle) and the photogrammetric processing for the creation of the DSM and orthophoto products.

### 2.1 Measurement of GCP's

The study area consists of Dhaskalio, the islet opposite Keros, and the location Kavos on the island of Keros. In the area of Dhaskalio a number of 129 control and check points were established, while on the site of Kavos the number of GCP's were 105, most of them placed on the special deposit South and North (Figure 2). The coordinates of these points were measured with traditional surveying methods, using a laser total station reflectorless TCR305 Leica, with an accuracy of 2cm in planimetry and height. These points were tennis balls, stuck with nail in the ground, as well as, special plastic targets used in archeological trenches. The points were distributed properly in order to cover all the study area and so as to be easily identified in all images. Figure 5 shows the distribution of the control and check points for each study area.

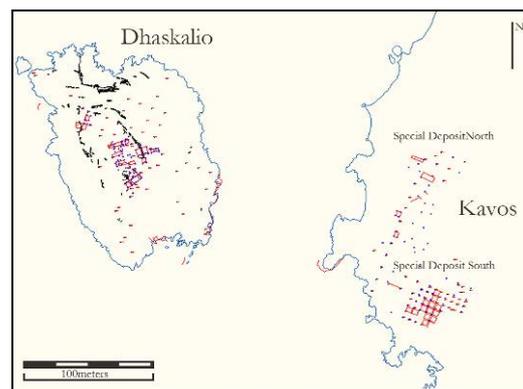


Figure 5: Distribution of control and check points.

### 2.2 Image acquisition

For the photogrammetric documentation of the study area an autonomous UAV (Unmanned aerial vehicle)-helicopter (figure 6), equipped with a digital camera, was used. UAV-based data acquisition technique is commonly used in photogrammetric recording and documentation of cultural heritage. Considering the capability to combine aerial and terrestrial acquisitions with the authority of flying nearby the object from different positions and angles, UAVs are a substantial tool for image acquisition.

Moreover, the fact that they can be navigated to the predicted acquisition points with low cost GPS/INS systems makes UAVs an economical, fast and efficient technique for site recording.



Figure 6: The UAV-helicopter used for the image acquisition.

The camera mounted to the helicopter was the 10.1 Mpixel (3888 x 2592) Canon EOS D400, which was placed on a special platform in order to eliminate the vibrations of the helicopter and allow the 360 degrees rotation in horizontal and vertical direction. The camera was calibrated and the calibrated focal length was  $c=9.056\text{mm}$ . For ensuring sufficient image overlap and an overall view of the area, the signal of a video camera, installed on the helicopter, was transmitted to the ground control station via RF and displayed on a monitor. The activation of the shutter for acquiring the images was controlled from the ground unit. Due to time restrictions in the acquisition of the data e.g. the archaeological excavations were reaching the end, thus the archaeological trenches had to be covered. The flight was completed as fast as possible considering all the parameters influencing the acquisition of the data e.g. weather, sun reflection and radiometry.



Figure 7: Image showing the archeological trenches in Dhaskalio.

For the production of the final orthophotos at a scale of 1:500 in both study areas, images acquired from an average flight height of 20meters corresponding to an average image scale of 1:2000. The ground coverage in each image 1:2000 was 49.94x33.30m. As far as the image processing is concerned, a number of two strips with 7 and 13 photos of which 6 and 4 photos respectively were used. In addition, in order to create orthophotos in special areas of interest e.g. individual archaeological trenches, at a scale of 1:50, images 1:1000 acquired for an average flight height of 10meters. The ground coverage for this scale is 24.97 x 16.65m. Overall, in Kavos site (Special Deposit North and Special Deposit South) the largest image scale was 1:1000 while the smallest was 1:1500.

Area	No. of Strips	No. of images in each strip	No. of used images
Special Deposit South	4	9	4
		17	3
		17	3
		11	-
Special Deposit North	3	11	5
		13	4
		28	7

Table 1: Number of images in each strip for the documentation of Kavos site.

All the strips of images in both study areas were acquired with approximately 60 % overlap along and 30 % overlap across the strips. The images were already downloaded in the field in order to ensure image quality (no blurring due to movement of UAV, no saturation due to overexposure, no sun reflection).

### 2.3 Photogrammetric processing

The photogrammetric processing includes a number of digital photogrammetry applications such as tie point measurement, bundle adjustment, DSM and orthophoto generation. All the works were completed using the software package LPS 9.0 (Leica Photogrammetry Suite), a complete software for all photogrammetric processes.

Initially, for both study areas the process of Block Triangulation was performed concerning one strip at a time. As far as Dhaskalio is concerned the initial standard deviation of GCPs was 2cm while the accuracy of image point standard deviation was 2 pixels. The Bauer's simple model was used as an additional parameter function. In the procedure of bundle adjustment a total amount of 12 control points and 144 tie points were used.

Because of the steep terrain of Dhaskalio islet, DTMs were created for each individual strip and merged afterwards (figure 8). In addition to finalize the DTM so as to improve orthophoto's quality it was edited. The cell width varies between 0.5 and 3m and the general mass point quality for most of the points was 80 %. The final step comprises of orthophoto derivation. For the resampling process a pixel size of 2cm. Figure 10 shows the final orthomosaic of islet Dhaskalio.

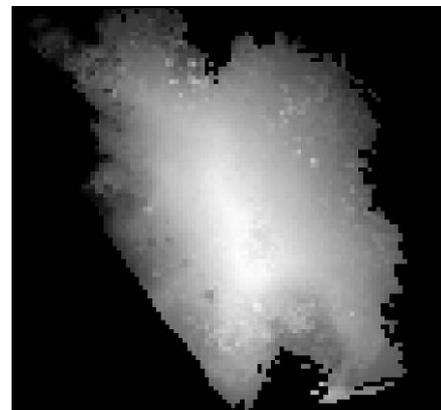


Figure 8: The Digital Terrain Model of Dhaskalio.



Figure 9: Orthomosaic of islet Dhaskalio.

As far as Kavos site is concerned, a similar photogrammetric process was accomplished. In this case, there were two separate blocks, one for the Special Deposit South area, and one for Special Deposit North area of interest. DTMs were extracted for both areas and finalized with DTM function “DTM editing”. The final step comprises also of orthophoto derivation. Figure 10 shows the final orthomosaic of Special Deposit South.



Figure 10: Orthomosaic of islet Dhaskalio.

### 3. REMOTE SENSING APPLICATION

A high resolution QuickBird Image was used to create an orthoimage with pixel size of 0.6m and accuracy better than 0.8 pixel showing Keros and Dhaskalio at a scale of 1:5000. The QuickBird Image was georeferenced to EGSA87 (GGRS87), the projection system that is used nowadays in Greece.

For the geometric correction and georeferencing of the QuickBird Image (figure 13), 5 up-to-date cadastre maps 1:5000 (figure 11) and a Digital Terrain Model (DTM) of the whole area of interest (figure 12), provided by The Hellenic Military Geographical Service, were used. The georeference of these maps to EGSA87 took place using all grid points in each map. During the process of the ortho resampling of the QuickBird Image in the commercial software package Erdas Imagine 9.1, the rectified maps 1:5000 were used for the determination and measurement of Ground Control Points (GCP's), as well as the Digital Terrain Model (DTM) of the whole region.

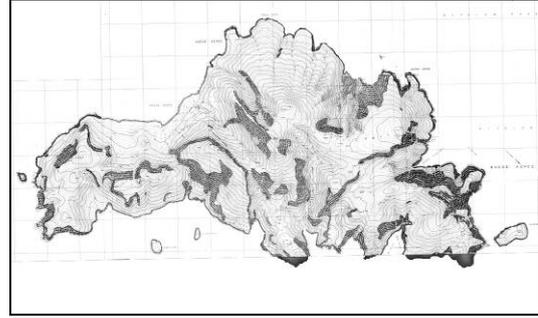


Figure 11: The mosaic of cadastre maps 1:5000 showing Keros and Dhaskalio.

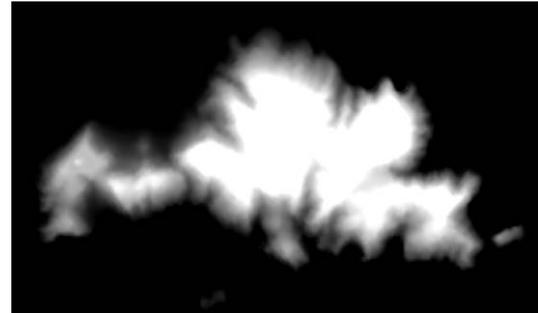


Figure 12: The Digital Terrain Model (DTM) of Keros and Dhaskalio.



Figure 13: The Quick Bird Image showing Keros and Dhaskalio.



Figure 14: Screen captures of a flythrough video showing Keros and Dhaskalio using the QuickBird Image.

### 4. LASER SCANNING APPLICATIONS

During the Keros-Dhaskalio project we used laser scanning for three different applications, in the excavation site. Two of the applications involved terrestrial laser scanning for the modelling of specific places. The first task was the production of a DTM for the excavation site, while the second was the detailed modelling of some trenches. For these applications we used the Optech ILRIS 3D laser scanner, while the third one was the modelling of 6 pre history Cycladic figurines using a NextEngine laser scanner.

#### 4.1 Laser scanning DTM collection and creation

For the DTM collection of the excavation site an Optech ILRIS 3D laser scanner was used. The topography of the excavation site was suitable for the usage of a laser scanner. The small island of Dhaskalio could be scanned from the higher sites in the island of Keros, while the Dhaskalio site could provide sites with a panoramic view of the excavation in the Keros island. The DTM grid was selected to be 20 cm. For the DTM creation of the Dhaskalio site 7 different scans were performed, while for the DTM creation of the Keros site 4 different scans were performed. The total number of points collected for the Dhaskalio DTM was approximately 4 million points while the final model was created using 433402 triangles. The point cloud alignment and registration was performed using the Polyworks software, while the final merged model was inserted in the Geomagic Studio software for texturing and hole filling. Figure 15 shows a view of the final 3D model of the Dhaskalio Site.



Figure 15: 3D model of the Dhaskalio Site.

For the DTM production of the Keros site 4235632 points were collected while the final model was comprised of 2625212 triangles. The whole processing was done using the polyworks software. The final model of the DTM for the Keros island is demonstrated in figure 16.



Figure 16: 3D model of the Keros Island.

#### 4.2 Laser scanner modeling of trenches

During the project we created models of two different trenches of the excavation site. For the first trench we performed 9 different scans using a 5mm grid collecting 5651133 points while the final model that was created using the Geomagic Studio 10 software had 4243134 triangles. In figure 17 we can see a view of the 3D model of the first trench.

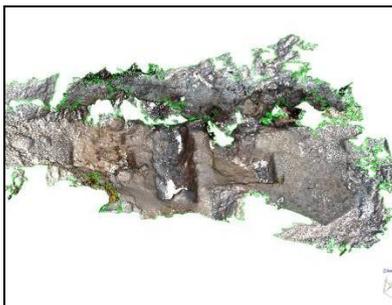


Figure 17: 3D model of the first trench.

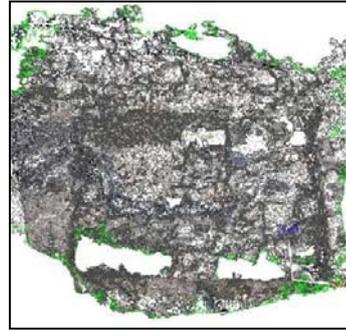


Figure 18: 3D model of the second trench.

For the second trench we performed 8 scans collecting 2639840 points while the final model had 588792 triangles. The 3D model of the second trench is represented in figure 18.

#### 4.3 Laser scanning of Cycladic figurines

Additionally to terrestrial laser scanning application we also modelled 6 pre history Cycladic figurines using the NextEngine scanner. Our goal was to identify traces in the figurines surface that can give hints to archaeologists about their usage. In order to achieve that goal we had to create models of high detail. The NExtEngine scanner is capable of scanning object with a dimensional accuracy detail of 127  $\mu\text{m}$  and a grid of 63.5  $\mu\text{m}$ . In table 2 we can see some statistics about the scanned data of the figurines. The 3D models were created using the Geomagic Studio 10 software, using the camera data of the scanner to produce photorealistic texturing.

# of scans	# of points	# of triangle	Image texture
12	2491126	512784	No
15	1808070	625046	No
12	3018548	1262982	No
21	2132908	449312	No
14	1079921	319570	No
29	4852916	1367192	No

Table 2: Statistics for the modeled figurines.

As we can see the number of scans was around 15 scans per object, except the last object which was a special case. The last object was a broken figurine head, so we have to scan the two fragments separately and produce a 3d model of each one. We also performed a scan with the two fragments joined and finally we registered the two separate models in a final one figure 19.



Figure 19: 3D model of the fragmented figurine.

In the next figures we can see some of the 3d models that created during the Dhaskalio-Keros project. The final 3d models were converted to 3d-pdf format, which gives the ability to users to perform basic measurements to the object, change the display of the model, and also create cross sections, while the size of the file is quite small compared to VRML files thus giving the opportunity to specialists to examine the models using free distributed software.



Figure 20: 3D model of figurine's torso.



Figure 21: 3D model of an artifact.

## 5. CONCLUSION

In this study we presented an application of different surveying and 3D modeling techniques in an archaeological site. We processed data in different scales. We produced an orthoimage with 0.6 m size using a QuickBird satellite image. For selected regions of the excavation we produced DTM and orthoimages using photogrammetric techniques. The resolution of the orthoimages was 2cm. The different scales of the orthoimages were selected based on the needs of the archaeologists for different levels of details according to the importance of the regions. We also applied laser scanning techniques to model the whole excavation site with a resolution of 20 cm while for specific trenches we produced detailed 3D models with a resolution of 1 cm. Finally we created accurate high detailed 3 dimensional models of excavated Cycladic figurines. The whole project resulted in a detailed documentation of a part of the excavation site, giving models with different level of details, starting with the excavation site, the detailed models of specific trenches and concluding with high detailed models of excavated artifacts.

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