Photogrammetric Record, 16(93): 443–456 (April 1999)

THE PHOTOGRAMMETRIC SURVEY OF A PREHISTORIC SITE UNDERGOING REMOVAL

By A. GEORGOPOULOS, G. E. KARRAS and G. N. MAKRIS
National Technical University of Athens

(Paper read at the Thompson Symposium of the Photogrammetric Society held at the University of Durham on 18th April, 1998)

Abstract

For the construction of the new Athens International Airport, it was imperative that a hill, obstructing air traffic, be lowered by approximately 40 m. Unfortunately, a fortified prehistoric settlement was situated on top of that hill. In order to carry out this task, it was required: (a) to produce a model of the site at a scale of 1:50; and (b) to monitor and document every single stone during the dismantling of the most important parts of the site, so that its rebuilding elsewhere and at a later time would be possible.

The Laboratory of Photogrammetry, National Technical University of Athens, undertook to provide the necessary metric data. By using low altitude aerial photographs from a helicopter, a specialized tripod and terrestrial photogrammetric techniques, the following products were created, all at a scale of 1:50: contour lines and DTM of the site; digital orthophotograph of the site; graphic drawing of the development of the exterior of the surrounding wall; and graphic drawings of the upper (initial) and the lower (last) levels of the parts to be removed. In this paper, both the fieldwork and the final products are presented and evaluated.

KEY WORDS: digital orthophotography, terrestrial survey, low altitude photography

INTRODUCTION

AS WITH MOST major construction projects in Greece (for instance, that of the Athens metropolitan subway now in process), the new International Airport of Athens had to pave its way through confrontations with history. Regrettably, the top of the Zagani hill, which had to be "lowered" by some 40 m for reasons of flight safety, happened to be the location of a very important prehistoric site. This outstanding settlement of the Early Helladic 1 period (approximately 2700 BC), the remnants of which covered an area of about 80 × 80 m, was indeed one of the rare fortified settlements of its kind in Greece (Fig. 1). The Ministry of Culture finally decided, not without arousing heated discussions, that the settlement should be dismantled and, with its stones having been carefully numbered and recorded, partly restored in the Airport's

FIG. 1. Oblique aerial view of the site on Zagani Hill before its removal.

museum at a later time, together with an exact 1:50 replica of the whole site. The accurate geometric documentation was also necessary for a further reason, namely as a basis for the archaeological study which could not be concluded *in situ* due to the very tight time schedule of the project.

Photogrammetric documentation techniques were the obvious choice, providing answers to requirements for both accuracy and (above all) speed. The stones were removed in "layers", revealing new levels which had to be recorded instantly from above for the excavation to continue. Often, image acquisition was required twice a day and paper prints had to be available the next morning to check image quality. This lasted for more than two months involving, on a daily basis, a team of four for image acquisition and related surveying work. Furthermore, the whole site had to be documented with regard to both planimetry and relief, while the development of the 150 m long outer wall also had to be plotted. Fieldwork took three months, followed by another three months of intensive laboratory work.

The documentation was designed for the scale of 1:50, due to the importance and the nature of the object. It was based on a combination of various digital photogrammetric techniques, supported by dense surveying measurements (more than 1500 signalized points had to be measured for control purposes). Thus, according to the demands of each particular task, images were taken with different cameras from a multiformity of platforms and were processed by a variety of techniques.

For the overall documentation of the site, helicopter photography with a large format terrestrial metric camera was adopted (resulting in more than 100 images from three different altitudes); the resultant images were processed within a digital photogrammetric workstation. Based on the automatically generated DEM at 0·25m spacing (the peculiarities of the relief dictated extensive editing which will be discussed later), the final products were a digital contour plot of 0·25m vertical interval which, among its other uses, constituted the basis for the replica (which is now complete) and a digital 1:50 scale orthomosaic for planimetric documentation.

For a more detailed representation of the two densely constructed settlement areas (where height differences did not exceed 1 m), the successive "layers" of stones brought to light during excavation (down to the bedrock) were stereoscopically covered with vertical images using a medium format non-metric camera carried by an 8 m high tripod. A total of 350 photographs was taken in this context. All stereopairs of the initial and final "layers" were evaluated in a small digital system with stereoviewing facilities; for the intermediate levels, images and control information are available for archaeologists for future metric exploitation if and whenever required.

Finally, the 150 m long remaining surrounding wall of the settlement (<1 m high) and all interior walls of the rooms were recorded on 25 roll films with a 35 mm amateur camera, thus producing a total of 850 photographs. The images of the outer wall were plotted monoscopically, rectified and mosaicked into a continuous development. For this task, a specially designed planar control frame, made of plexiglass, was employed. With two points measured topographically for each exposure, the positions of the remaining control points were fixed in space as the device was held vertically in contact with the wall.

PRODUCTION OF CONTOUR PLOT and DIGITAL ORTHOPHOTOGRAPHY

Planning and Executing Photography

Careful planning for the helicopter photography was required in order to cover the area as efficiently as possible, while at the same time maintaining similar scale, small rotations and, consequently, securing the required final accuracy.

TABLE I. Summary of helicopter photography.

Flying height (m)	*Scale*	*Number of images*
30	1:300	75
75	1:750	10
95	1:950	8

Flight planning was executed on an old 1:100 scale plot of the area. The flight lines and the planned image centres were determined on the plot and later signalized on the ground with specially prepared targets. The forward overlap was decided to be 80 per cent in order to allow for errors in the position and orientation of the helicopter. The dense network of control points was also premarked on the ground, with targets coloured differently from the projection centres. This proved very useful, because the camera operator was able to use these points as reference points for instructing the pilot. The operator was in constant contact with the pilot, thus achieving the proper orientation of the helicopter based on the premarked points on the ground before each exposure. The photography was taken on black and white film with a Wild P31 terrestrial camera specially mounted on the helicopter skid (Fig. 2). This camera uses cut film and the cassette had to be changed for each photograph, while the helicopter was hovering over the area. For every photograph, approximately five minutes were required.

Five strips from an altitude of 30 m above ground were required to cover the area at a scale of 1:300, which is sufficient for the 1:50 scale final products. The altitude was determined with the help of the helicopter's altimeter. Additionally, further coverage was carried out from altitudes of 75 m and 95 m, in order to obtain overview images (which in fact turned out to be indispensable). The coverage of the area required approximately eight flying hours carried out in two days. In Table I a summary of the imagery acquired is presented.

Digital Processing of the Helicopter Photography

Initially, the images from the lowest altitude were scanned with a desktop A4 size scanner at a resolution of 600 dpi. This resulted in a pixel size of 13 mm on the ground, which was considered adequate for the final scale. The digital images were introduced to a Vision SoftPlotter digital workstation; they were initially oriented as strips and later as a block. The accuracy of the orientations, given the large number of control points (12 points per picture), was quite satisfactory, resulting in r.m.s. errors of the order of 9 mm. However, probably due to miscalibration of the helicopter's altimeter, one edge strip was at a considerably larger scale, leading to failure of complete coverage. Moreover, for approximately 35 per cent of the images, SoftPlotter refused to produce epipolar images for inexplicable reasons. Although Vision itself was unable to give an explanation, it was thought that the software uses an approximate algorithm, employed to adjust the photogrammetric observations, instead of a rigorous one. Since the rotations of the particular images exceeded the usually assumed small values ($\pm 3^g$), the software was unable to process them.

Fortunately, the area was also covered from higher altitudes. Five of the 95 m images were scanned on a PhotoScan PS1 photogrammetric scanner at a resolution of 1200 dpi. This resulted in a pixel size of 20 mm on the ground, which was just adequate for the final scale. Control points for their orientation were determined from the previously oriented strips. The block of these five images was satisfactorily oriented and the epipolar images were also produced with no problems.

FIG. 2. The Wild P31 camera mount on the helicopter skid.

Image matching for the DTM production was the next step. Two different DTMs were produced from the 95 m photography, one to obtain the contour plot and one for the production of the orthophotography. For the former, all construction details (such as walls and stones) were ignored, because the requirement specifically called for contours of the ground itself, in order to provide the necessary basis for the construction of the replica. All points of the digitally produced DTM determined on the man-made structures were excluded and replaced by neighbouring points at ground level. For this DTM, no breaklines were needed. This intermediate product was subsequently processed with the QuickSurf software, which operates within the AutoCAD environment, to produce the 0·25 m vertical interval contour plot of the area (Fig. 3).

The second DTM, at a vertical interval of 0·2 m, was produced for the orthophotography. This raw DTM was not suitable for orthophotograph production, because approximately 55 per cent of the points determined were wrong. The DTM was manually edited and new points were added where necessary. Moreover, careful introduction of suitable breaklines was also carried out in order to take into account even the finest height differences of the stonework. In this respect, all walls and large stones were described by breaklines in detail. This has been a necessary, although time consuming, task. A larger number of breaklines was needed at the edges of the models to allow for stronger relief displacements. Using this corrected DTM, five orthophotographs with a pixel size of 20 mm were produced covering the whole area

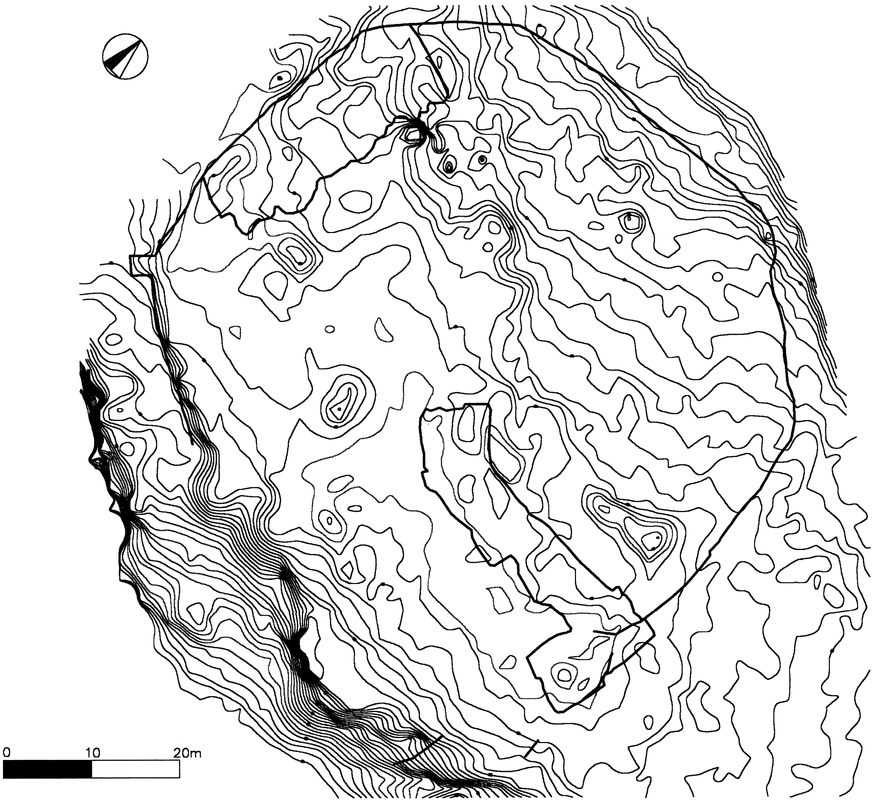


FIG. 3. Contour plot of the area (0·25 m vertical interval).

of the settlement. These five images were mosaicked within the SoftPlotter environment, which provided for grey tone equalization. The final orthophotograph was cut into six 1 : 50 scale sheets and was plotted on special glossy photographic paper with an HP Designjet 2500CP colour inkjet plotter. The final product (Fig. 4) was also plotted at 1 : 100 and 1 : 200 scales.

DETAILED SURVEY OF THE LAYERS DURING REMOVAL

Low Altitude Photography with a Tripod

After the general survey works for the production of the contour plot and the orthophotography had already started, the archaeologists decided to remove some parts of the monument. The removal needed to be performed in a way which allowed reconstruction elsewhere and at a later time. This requirement called for even more detailed documentation of these specific parts, which were the most important ones. They formed two areas A (600 m^2) and B (500 m^2), each of which consisted of several rooms.

The dismantling would be carried out in layers, so that the archaeologists would

FIG. 4. The final orthophotograph.

remove the structures one layer at a time, while numbering each individual stone at the same time. Every layer ought to be recorded stereoscopically for an eventual restitution at a later stage. However, it was decided that drawings should be produced for the uppermost and the lowest (the bedrock) layers.

The most obvious and economical solution would be to use a light non-metric camera of medium format (60×60 mm) specially mounted on an 8 m high tripod (Fig. 5). For the purpose of this coverage, an initial photographic scheme for both areas was drawn up, such that the areas were covered stereoscopically from a height of 7·50 m with 65 per cent overlap. This scheme was maintained throughout the dismantling. In addition, the required positions of the control points (six per model and about 30 in total for each area) were also determined. After each layer was exposed, control points were added (in case they were removed with the stones) and they were all measured immediately after the photography. Having determined in advance the exact positions of the projection centres, coverage of the exposed area was relatively simple. Each photograph was numbered using a specially devised coding system and every image was taken twice for safety purposes. The stereoscopic

FIG. 5. The special tripod for low altitude photography.

coverage of each area and the geodetic measurements of the control points lasted, weather permitting, for about 30 minutes which was the maximum delay of the archaeological work. This task called for the continuous presence of a party of four while the dismantling took place over two months. The black and white films were developed and printed overnight for control purposes.

Photogrammetric Processing

The photogrammetric restitution took place on a Leica DVP digital photogrammetric workstation. Although the images were taken by a non-metric camera, their large scale (1:150) and the good quality control points in each model resulted in quite satisfactory orientation results, with r.m.s. errors of less than 10 mm in *X*, *Y* and *Z* (Table II).

A skilled photogrammetric operator undertook the difficult task of digitizing every single stone, large or small, appearing on each model. This procedure lasted for approximately 45 working days, or one day per model. Some editing was required afterwards to produce the final result (Fig. 6).

RECTIFICATION AND DEVELOPMENT OF THE OUTER WALL

Being an important feature of the fortified settlement, the surrounding wall had to be separately documented at 1:50 scale. Its outer surface was reasonably vertical and smooth, while following an irregular course in planimetry. Archaeologists required a development as an end plot; hence the outer surface was regarded, to an acceptable approximation, as consisting of a succession of vertical planar patches. The latter were defined by means of a specially designed planar control frame of

TABLE II. Statistics for 47 non-metric models.

Error type	R.m.s.e. (mm) X	Y	Z	Number of GCPs per model
Mean	7·77	7·96	8·11	5·36
Minimum	2	2	1	3
Maximum	17	15	33	8

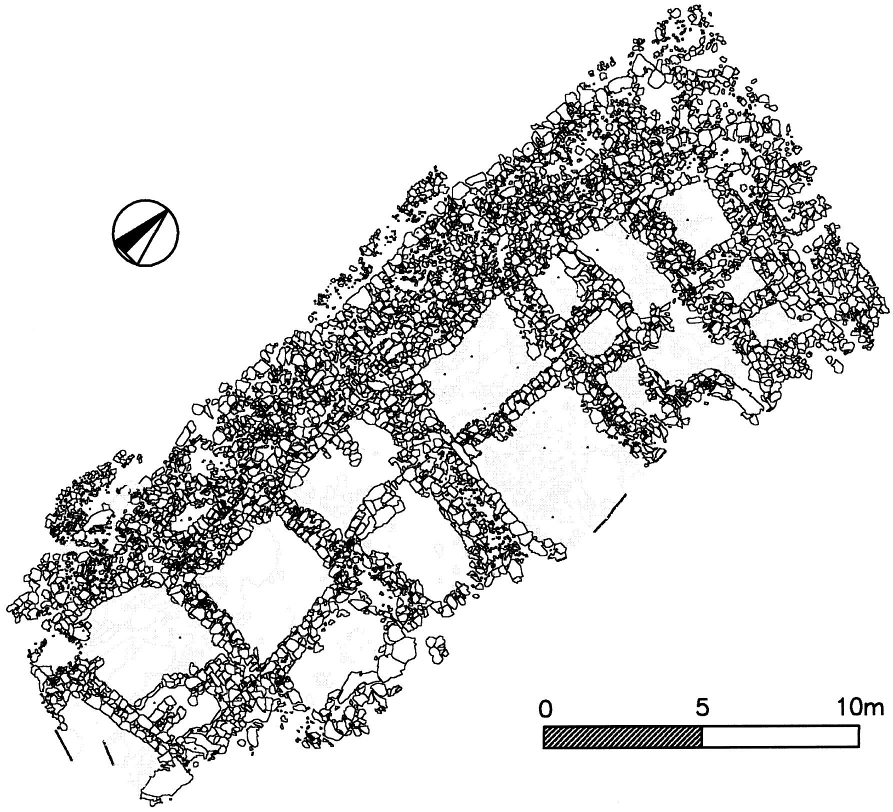


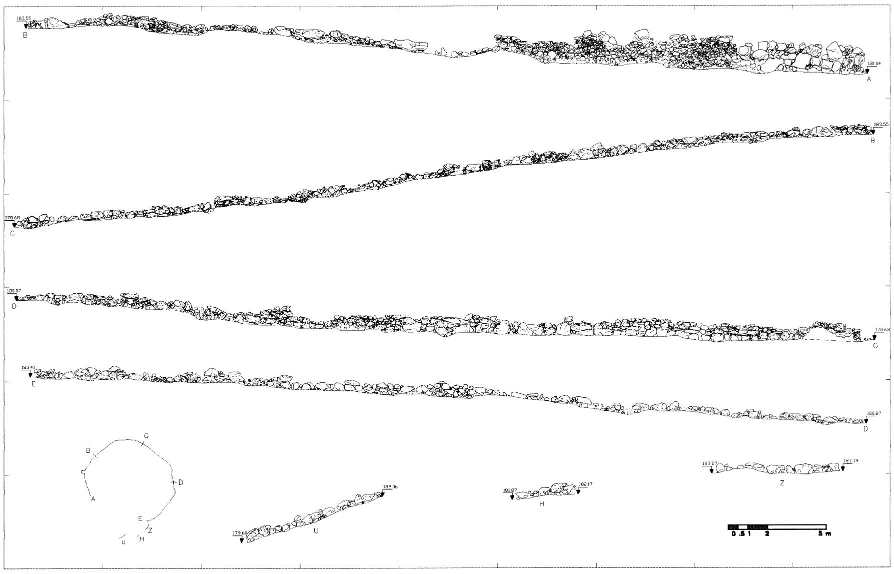
FIG. 6. Graphic drawing of one of the parts undergoing removal.

dimensions 2·5 × 1·2 m, made of plexiglass (Fig. 7). Photography was carried out with a hand held Minolta 35 mm non-metric camera with a 50 mm normal angle lens, from a distance of approximately 4 m. During photography, the frame was held vertically in contact with the wall surface; in this way it defined the specific plane of projection to be employed for the image in question. This control device carried seven well distributed control points; coplanar with these, two vertical holes on either upper side of the frame had been drilled, into which reflectors could be repeatably secured. These points, defined by the reflectors and measured topographically for the position of every individual frame at the time of exposure, were sufficient for fixing the seven

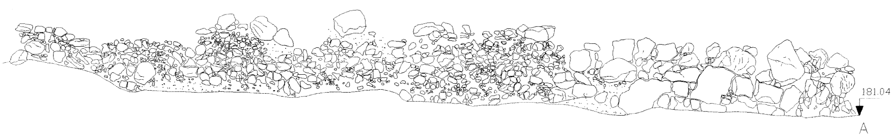
FIG. 7. The plexiglass frame.

signalized control points of the frame in space, given their known relative positions to the reflectors and the assumed verticality of the frame. Thus rotations of the frame in its own vertical plane (unavoidable due to local slopes) could also be taken into account. As a result, this simple technique allowed all images to be provided with reliable ground control (coplanar for each image) in the common geodetic system. As the geodetic measurements were carried out from only three survey points in the area, the saving on fieldwork was immense.

The transparency of the frame was intended to allow convenient plotting; indeed, the frame did not reduce image quality or cause occlusion problems. However, a second image was taken instantly, after removal of the frame, from the same position with the hand-held camera for future use by archaeologists. At a later stage, the images were scanned at a resolution of 600 dpi on a desktop A4 scanner and the stones were then digitized within a CAD environment, together with the positions of the control points on the frame. Vectors were subsequently rectified to their corresponding projection planes and, finally, all projectively transformed detail was merged into a file of vector development representing the final product for the perimetric wall of the settlement (Fig. 8). Obviously, this end product is the result of considerable editing efforts due to uncorrected perspective distortions caused by the non-planarity of the object. It is noted that in such cases vector rectification is, of course, preferable to raster rectification which would only complicate matters. The accuracy of the result is mainly dependent upon relief and it varies locally. Any inaccuracy is inherent in the monoscopic treatment of the non-planar object as well as the "unfolding" of a surface which, strictly speaking, is not developable. This plot was also used for the reliable representation of the outer wall on the replica.



(a)



(b)

FIG. 8. (a) The development of the outer wall. (b) Detail of (a).

Finally, the walls of the rooms were fully recorded monoscopically on images with sufficient control; they wait, as a potential witness, to be called upon by the archaeologists responsible for the site in the course of their ongoing investigations.

CONCLUDING REMARKS

It is believed to be the first time, in Greece at least, that an archaeological site has been geometrically documented to such an extent. Apart from the metric aerial photographs, oblique documentation photography and video were also taken from the

TABLE III. Metric images acquired and geodetic measurements performed.

Survey type	*Equipment*	*Number of images/observations*
Helicopter	Wild P31 with 100 mm lens	100
Tripod	Hasselblad MC1 with 50 mm lens	350
Terrestrial	Minolta 35 mm with 5 mm lens	850
Geodetic measurements (control points, frame positions)	Wild TC1610 + DIOR 3002	1500

helicopter. Moreover, from all the photogrammetric images acquired, only a mere 30 per cent were processed. The rest will be kept for eventual later evaluation, if necessary. In Table III, the total quantity of photogrammetric images and geodetic measurements is presented.

For the execution of this project, a party of nine surveyors and one specialized photographer were in constant co-operation with the archaeologists and architects responsible for the site for the two months of the fieldwork. Moreover, the civil engineers of the company responsible for the construction of the airport were also involved, either to provide technical support or to reduce the time required for each task. Hence, this project has been a very good example of interdisciplinary co-operation.

During the course of the works, a method for the production of the elevation drawings of the vertical elements of the site (outer wall and other walls) was devised and employed in order to save fieldwork. It is estimated that the use of the plexiglass frame saved the establishment of some 50 extra traverse points and the determination of approximately 1500 control points, at least on the outer wall, with all related measurements and calculations.

All geometric information, either directly measured or indirectly determined, together with the qualitative information registered on the photographs, proved to be more than adequate for the support of the construction of the impressive replica (Fig. 9), as dictated by the Central Archaeological Council of Greece. It is worth mentioning that, although both metric and non-metric photography were employed, the final results are well within the initial specifications for the scale (1:50). Superimposition of the photogrammetric plot on the orthophotograph revealed that there were maximum planimetric differences of 20 mm. Finally, photogrammetry has provided all the necessary quantitative and qualitative information for the reconstruction of the parts removed, wherever and whenever may be decided in the future.

Today, these results (and, of course, all further products which may eventually be drawn from the fully documented photographic material now archived) represent the sole reliable geometric as well as photographic evidence of what, for centuries on end, has been the prehistoric settlement of Zagani. With this example, the important potential of employing photogrammetry for the documentation of archaeological sites is illustrated, although one would certainly prefer to exploit it for documenting what is to be preserved and not that which is doomed to destruction.

ACKNOWLEDGEMENTS

The indispensable contribution of our photographer, Mr. D. Chliveros, the patience of our pilot, Captain D. Prentzas, and the financial support of the Athens

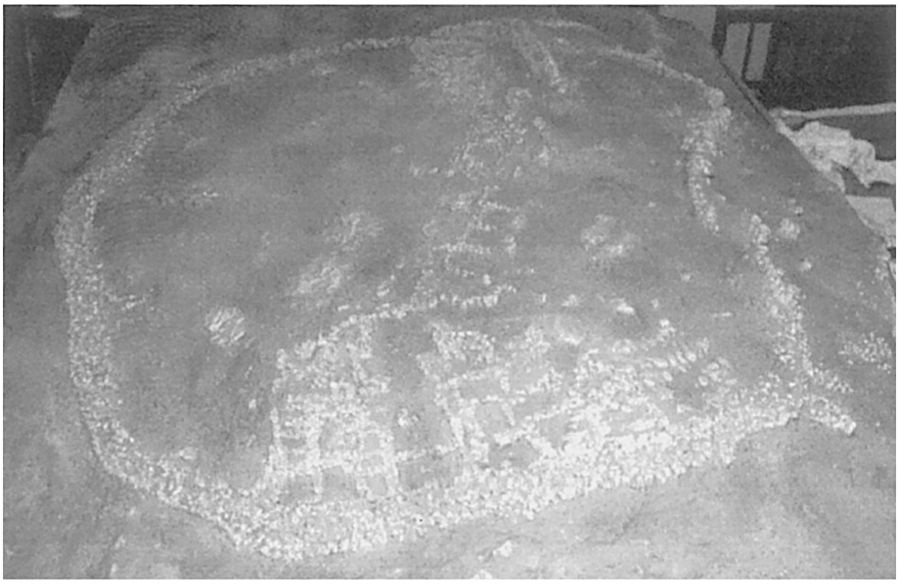


FIG. 9. The 1:50 scale replica of the site.

International Airport S.A. are gratefully acknowledged. Our debt to the archaeologists of the 2nd Ephoria of Prehistoric and Classical Antiquities is more than obvious. The project would not have been completed without immense help from our competent colleagues Messrs. C. Paganis, D. Mavromati, E. Tsiligiris, G. Pantazis and E. Lambrou.

Résumé

Pour la construction du nouvel aéroport international d'Athènes, il était nécessaire d'abaisser d'environ 40 m une colline qui faisait obstacle au trafic. Malheureusement un site préhistorique fortifié se trouvait juste au sommet de cette colline. Les conditions requises pour effectuer ce travail furent: (a) de modéliser le site à l'échelle de 1:50; (b) de renseigner et de suivre chaque pierre séparément pendant le démantèlement des éléments les plus importants du site de façon à pouvoir le reconstruire ailleurs ultérieurement. Le laboratoire de Photogrammétrie de l'Université technique nationale d'Athènes entreprit de fournir les données métriques nécessaires. En utilisant des photographies aériennes à basse altitude prises en hélicoptère, un trépied spécial et des techniques de photogrammétrie terrestres, on a réalisé les produits suivants, tous à l'échelle de 1:50: des courbes de niveau et un MNT du site; une orthophotographie numérique du site; une représentation graphique de l'aménagement à l'extérieur du mur de l'enceinte; et des dessins graphiques des parties à déplacer, en commençant par les niveaux supérieurs qui partent les premiers puis en finissant par les niveaux inférieurs. On décrit dans cet article les travaux de terrain ainsi que les produits finaux et on les évalue également.

Zusammenfassung

Für den Bau des neuen internationalen Flughafens von Athen erwies es sich als erforderlich, einen Berg, der den Luftverkehr behinderte um ungefähr 40 m abzutragen. Unglücklicherweise befand sich eine befestigte vorhistorische Siedlung auf der Spitze dieses Berges. Um diese Aufgabe zu lösen war es erforderlich, (a) ein Modell der Örtlichkeit im Maßstab 1:50 anzufertigen, (b) jeden Stein während des Abtrags der wichtigsten Teile der Anlage zu erfassen und zu dokumentieren, so dass ihr Wiederaufbau irgendwo zu einer späteren Zeit möglich würde.

Das Photogrammetrielabor der Nationalen TU von Athen beschäftigte sich mit der Beschaffung der erforderlichen metrischen Daten. Unter Verwendung von Luftbildern aus geringer Flughöhe von einem Hubschrauber aus, einem speziellen Dreifuß und Verfahren der terrestrischen Photogrammetrie wurden die folgenden Erzeugnisse, alle im Maßstab 1:50, geschaffen: Höhenlinien, DTM und ein digitales Orthophoto der Anlage, eine graphische Darstellung des Äußeren der umgebenden Mauer und graphische Wiedergaben des oberen (anfänglichen) und unteren (endgültigen) Niveaus der abzutragenden Teile. In diesem Beitrag werden sowohl Geländearbeiten als auch Finalerzeugnisse dargestellt und bewertet.