

## **DETAILED 3D REPRESENTATION OF ARCHAEOLOGICAL SITES**

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### **ABSTRACT**

The compilation of detailed 3D representation of archaeological sites is of great importance either for documentation needs or for restoration purposes. The development of special tools and means and the appropriate use of the capabilities of Spatial Information Systems for the data classification, management and visualisation is indispensable.

An application of such procedures and techniques was done for the archaeological site of the Acropolis of Mycenae, which was the most important center of the prehistoric hellenism. The necessary 3D data are derived from the extant analog planimetric diagrams, produced in various periods of time and at varying scales, by photogrammetric procedures, stereoplotting and rectification of aerial photos taken by helicopter and terrestrial photos, and by field measurements, for the data completion.

The adjustment and 3D-editing of all geometric data was done by a CAD software. The product and its quality characteristics, as attributes, were used as input to a SIS, where the data manipulation is done. Proper interfaces and special scripts for semi-automatic interactive compilation of the 3D model of the Acropolis were written in the SIS environment. For the data visualisation the rendering operation of CAD and the existing operation of the 3D-scene modelling of SIS were used. The 3D views of the site were derived by fully automated procedures. A product which provides valuable and impressive tools for better documentation, with all the geometric data in 3D and in various thematic layers and a reliable data base for the support of various studies of the monument.

### **1 INTRODUCTION**

Since the era of analog and analytical photogrammetric instruments, the detailed plotting and evaluation of archaeological sites and monuments has been an issue of broad photogrammetric applications with considerable results. The use of Geographical and particularly Spatial Information Systems tools (Bruessler et al 1998) in combination with the development of digital automatic methods for data collection and management (Zhao et al 1998, Pollefeys et al 1999, etc) have rapidly increased the capabilities of integrated systems for the documentation and preservation of monuments and archaeological sites. The plain 2D plotting, no matter how detailed and accurate may be, constitutes only one type of SIS products or an input element for an interactive Decision Making System for the restoration of a monument. Despite the fact that 3-Dimensional representations are laborious and time-consuming, they are necessary in many applications (Ioannidis et al 1999) and this is where this paper will be focused on.

To face the difficulties of applying all the above mentioned considerations to a complicated monument or moreover to a large archaeological site, various types data collection methods must be used, such as: photogrammetric and field surveying, aerial and ground-based laser scanning, orthophotos, rectified terrestrial images and video images, giving various types of data in vector and raster format (Zhao et al 1998). By these means the first out of the four typical subsystems of a SIS, the data entry subsystem, is created.

For the development of the following two subsystems, the data storage and data analysis, the most important role has the level of automation of the procedures. For the construction of 3D representations the closest examples are the 3D city modelling attempts that have been developed and automated recently, giving well accepted practical results. Various methods and techniques were suggested and applied for that (Lammi 1996, Haala et al 1998, Gruen et al 1998, Gruen et al 1999). The development of commercial software packages was based on these techniques and applied at Zurich, Tokyo, Jerusalem, Scandinavia, USA and elsewhere. Also, experiments of international organizations, like OEEPE (Foerstner et al 1996), were focused on that. The generally accepted conclusion is that the best results were achieved by semi-automatic approaches, where the user performs parts of the data acquisition so helping the automatic

procedure over the difficult or impossible steps and a computer finishes any measuring and time-consuming tasks. Yet, for the transfer of such procedures to archaeological applications two basic problems are to be faced:

- the difference in plotting scale and due to that the difference in the details that have to be collected for a 3D representation. The generalization helps to the automation in the creation process of city models, but in the case of archaeological modelling it is little accepted
- the lack of uniqueness and predefined patterns in archaeological modelling, compared with the roofs of the houses or the terraces that exist in urban areas. The problem increases when the representation of the existent today situation of an archaeological site is needed, where a lot of ruins or semi-destroyed areas exist.

The only solution to that, is the use of less automated and more time-consuming procedures, with a parallel development of interactive methods and sophisticated interfaces for the user communication with the SIS.

For the particular application special emphasis is given to the fourth SIS subsystem, which refers to the data visualisation. This defines the way of data presentation and influences the data evaluation capability. More critical, it constitutes the criterion for the acceptance of the whole method by other disciplines-users, such as archaeologists, etc. The commercial software packages that are specialized on the 3D representation compilation have developed multimedia tools for the creation of impressive products and are compatible with almost all SIS data formats. Consequently they can be the basic additional tool of IS and through the development of some special interfaces they can provide us with the desirable results.

The performance and efficiency control and the application of the above mentioned techniques have been done for the archaeological site of the Acropolis of Mycenae, through a research project commissioned by the Ministry of Culture of Greece to the Laboratory of Photogrammetry of National Technical University of Athens. Various alternative solutions were tested at all stages of the system development, mainly about the possibility of automation of some time-consuming procedures and methods for the 3D representation.

## 2 THE ARCHAEOLOGICAL SITE OF THE ACROPOLIS OF MYCENAE

The archaeological site of Mycenae is one of the most ancient and impressive monuments of Greece. It was built on a natural fortification hill at the northeastern Peloponese, at a location from where all the existing basic road network and the sea transportation routes in the antiquity could be controlled. The city began to have power since the 19<sup>th</sup> century B.C. It was initially fortified by a cyclopean wall about the year 1350 B.C. One century later, the fortification was extended and the Acropolis acquired a new magnificent entrance, the Lions Gate, well preserved until today, which carries the most ancient sculpture in Europe. At the highest part of the hill, an extended palace was built, ruins of its parts are still preserved. In the Acropolis, which in various time periods was densely inhabited, a considerable number of houses, store-houses, laboratories, temples and shrines were built. The impressive Grave Circle of a previous era was also surrounded by a wall and was decorated by plaques standing vertical, which are there until today.

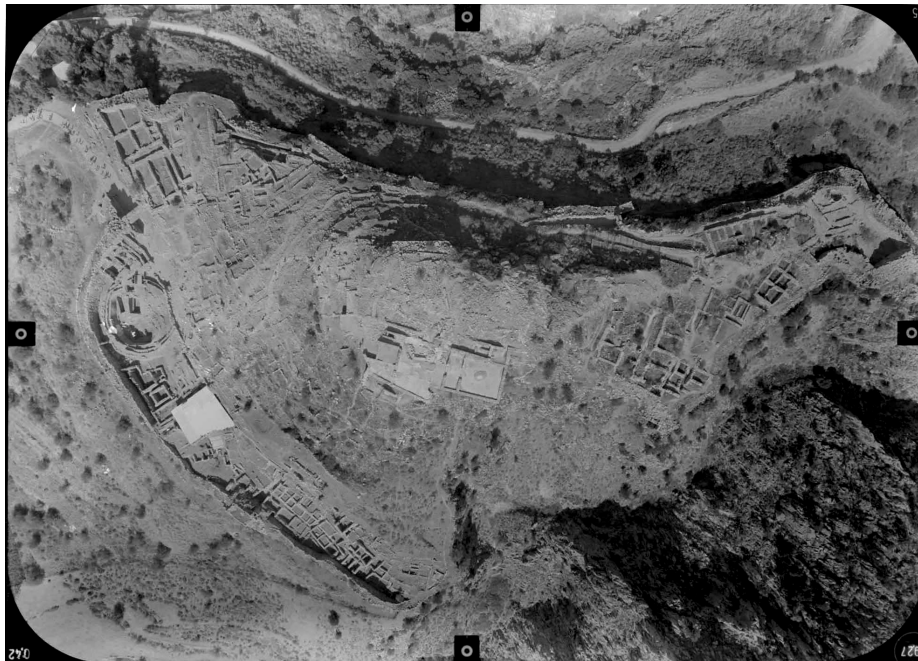


Figure 1. Aerial photo of the Acropolis of Mycenae taken by helicopter

Mycenae experienced various periods of prosperity and abandonment. It was rebuilt about the year 1000 B.C., destroyed in 468 B.C. and rebuilt again as a new hellenistic city at the 3<sup>rd</sup> century B.C. Mycenae was desolated forever since the Roman era. The highest percentage of the Acropolis, with a total area of 3.2 ha, is covered by ruins or foundations of constructions made during the prehistoric or hellenistic era. The maximum elevation difference of the surface terrain is approximately 30m. The biggest part of the external and internal cyclopean walls is preserved; the height of it in some points rises up to 6m. The external perimeter of the wall is 990m. The excavations in the area were started by H. Schliemann in the year 1876 and have been continued by the British Archaeological School and the Hellenic Archaeological Society. The excavations are not yet completed. In parallel fastening and restoration works are executed.

The target of the research project, undertaken by the Laboratory of Photogrammetry of NTUA, was the compilation of a detailed digital geometric documentation and 3D presentation of the present appearance of the Acropolis (Fig. 1). The most appropriate procedure to meet the requirements of the project is a combination of developing of a SIS together with the creation of a 3D model of the archaeological site.

### **3 DATA COLLECTION**

#### **3.1 General**

The most important factors that influence the selection of data collection methods for the required 3D geometrical data and the compilation of the SIS, are: the size of the monument, the degree of detail collection for its documentation, the existent terrain elevation differences and the leveling of the constructions, the complexity of the object and the level of its preservation. According to the characteristics given above, at section 2, about the Acropolis of Mycenae and to the required accuracy specifications (those of the scale 1:100), the application of a combination of extant relevant data of any kind, photogrammetric stereo-restitution or orthophotos produced by using large scale aerial imagery and field surveying or direct measuring is necessary.

As the extant data are not enough to satisfy the requirements of the 3D model creation, the most critical factor for the enhancement of data collection process is the maximization of photogrammetric methods contribution, which can achieve high automation and rapid 3D coordinate recording even manually. Field measurements should be limited only to those parts of the area that are not included into the aerial photos (such as the parts of the Acropolis that are sheltered for the protection of sensitive excavation finds) or where high relative accuracy between the neighboring monument elements is required.

#### **3.2 Available data**

All the scattered extant horizontal or leveling information has been collected. As in most archaeological sites, the available data was mainly planimetric information in analog form at a variety of scales, level of site detail capturing, accuracy and even unknown reliability. Data were collected from:

- 21 diagrams at scales varying from 1:50 up to 1:250, which had been compiled in arbitrary reference systems during the excavations made the last 35 years and covered most of the Acropolis. Most of them didn't mention at all any information about the drawing scale or the orientation, yet representing comparatively well the site details. They didn't always contain the whole of the extant information at that part of the site but usually only some particular parts selectively, such as of a particular era or of a certain structural phase. In addition to that, in some overlapping parts of the diagrams different data appear probably due to their different compilation periods regarding to the progress of the excavations. No leveling information existed on them
- 2 analog topographic diagrams, at a scale of 1:500. Due to their compilation scale, the generalization of the planimetric details and the poor availability of leveling information, restricted only to the terrain leveling, only some general data extraction was possible.

These diagrams were scanned and vectorized in various layers. Due to the variety of data, contained in most of these archaeological diagrams, not all of it referred to geometric information (i.e. hatching, shading of stones and rocks to show the relief, textual data etc), a semi-automated vectorization process was selected. A considerable volume of information was collected, yet scattered, not uniformly distributed, being of unknown accuracy and with insuperable matching problems. In addition to that, there was an absolute lack of any height information concerning the constructions above the surface of the terrain.

#### **3.3 The photogrammetric process**

For the three-dimensional coverage of all elements of the monument, it was necessary to have

- stereoscopic coverage of the Acropolis through large scale aerial photos and
- terrestrial photos of the facades of the walls selectively at the points of interest or with a difficulty in stereorestitution.

The aerial photos were taken by helicopter. The use of the metric analog camera UMK-Zeiss of large format 13x18cm, with focal length  $c=100\text{mm}$ , mounted on the helicopter skid by a specially designed base, was selected in order to diminish the number of photos. Taking into consideration the topography of the area and the locations of the objects of interest, 15 photos were taken from flying heights varying from 500m up to 1000m above the ground. Eight (8) stereomodels belonging to three different strips with considerable overlapping were used. Natural control points at characteristic spots were used in pairs (50 points in total). The processing of the stereomodels was done on a PC-based digital photogrammetric station and contained:

- the generation of a detailed Digital Terrain Model, by collecting leveling information manually
  - three-dimensional vector restitution of all parts of the monument at a detail level of a single stone of the masonry.
- These procedures were preferred rather than the automatic DTM generation and orthophoto mosaic compilation, due to the special characteristics of the object and the shape of the archaeological site:
- the high elevation differences and the density of the necessary break lines for the terrain relief representation
  - the great density of constructions, most of them are ruins with large height differences even between neighboring walls or along the same wall
  - successive constructions of various phases
  - the existence of 'dead' areas, which are created by the shelters established for the protection of the sensitive parts of the monument against rain and other climate phenomena
  - the blocks of stones that have collapsed and are scattered all over the area and the excavated material piled in the area for future reconstructions are changing the shape of the DTM.

The terrestrial photos were taken by the analog camera Rolleiflex 6006, with  $c=80\text{mm}$  and format 5.5x5.5cm, for more flexibility. Mono- or stereo-plotting was decided according to the object relief. The terrestrial photos covered mainly the internal side of the cyclopean wall, the plaques of the Grave Circle, the palace walls, facades of the sheltered parts of the Acropolis (at the area of the shrines) etc. Premarked control points were used, with rectangular targets of 5x5cm. Digital rectifications of the facades were compiled (using the ARCHIS/SISCAM software) and stereoplotting, too. The raster products were vectorized to be unified with the products derived from the aerial photos.

The products of all photogrammetric procedures were integrated into a unique 3D model of the site, which consisted of a specific layer-coverage of the 3D-SIS. By field control checks it was proved that r.m.s. of the 3D coordinates of characteristic points is less than 3cm. In Figure 2, a 3D representation of the surface model of the hill, where the Acropolis is built, is shown (without any kind of constructions) as it was produced by the DTM and the ground points measured on the terrestrial photos.

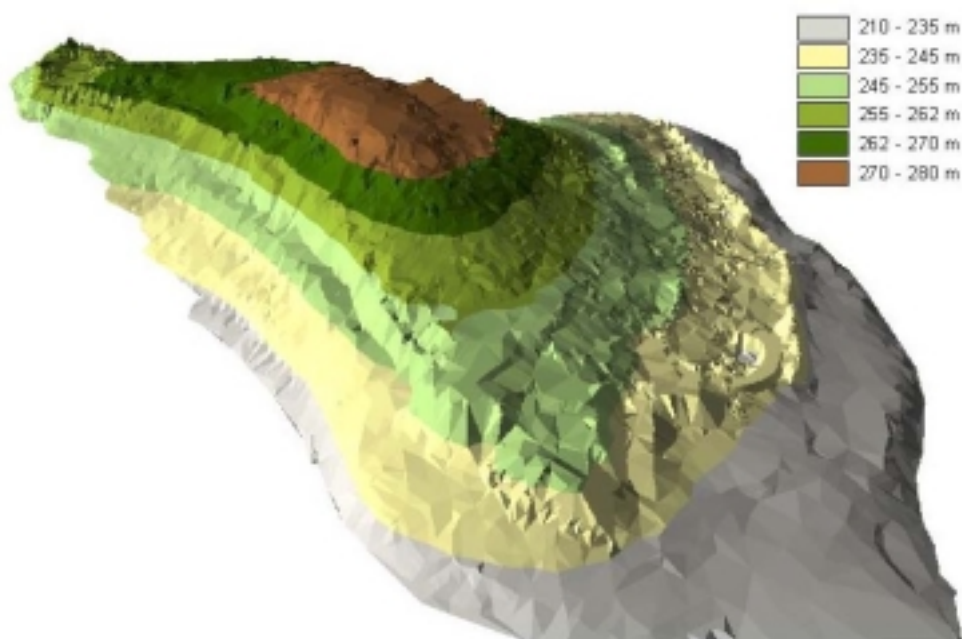


Figure 2. Northwestern view of the surface terrain model of the hill of the Acropolis

### 3.4 Field measurements

For the photogrammetric work and the integrated 3D restitution of the site, the following field surveying was done:

- Establishment of a 25 points network, dependent on the National Reference System
- Calculation of control points coordinates, for the aerial and terrestrial photos
- Calculation of 3D coordinates of detail points, at the parts of the Acropolis that are not in the photos. The combination of aerial and terrestrial photos has considerably decreased the area of those parts and consequently the laborious and time consuming procedure of the field work for the completion of the plans. Mainly the ruins of the construction foundations of the hellinistic era, where the masonry consisted of comparatively small stones, and which have a relief of approximately a few cm from the ground surface were measured
- Direct measurement of the height differences between the construction characteristic points and the ground, for those that were not photogrammetrically produced or by other field measurements.

The combination of the above methods led to the collection of all necessary data for the generation of a unique, complete, accurate and reliable digital 3D documentation of the Acropolis.

## 4 DATA MANIPULATION AND ESTABLISHMENT OF SIS

The merging and 3D editing of the geometric data was done by a CAD software (AutoCAD of Autodesk). The unique digital map of the site, derived by the combination of photogrammetric plotting and field completion, constitutes the basic information on which all the extant individual archaeological plans are adjusted. The adjustment was achieved by the application of affine transformations locally, after the local matching of certain characteristics of the planimetry, that existed in the old plans, with the relevant measured points. So, the orientation and a unique scale has been achieved for all data of the vectorized old diagrams. The additional existing geometric detailed information, about the construction and the architectural elements of the upper part of the walls and other constructions (open or covered water pipes etc), were incorporated into a unique file of the site. In parallel, the old plans provided codified significant information for thematic attributes of the parts of the Acropolis, such as their construction era, the use of each part of the site in antiquity, the layered construction phases in some buildings etc. The need for designing and developing a SIS, for the documentation of the archaeological site, is obvious.

The GIS-software ArcInfo and ArcView of ESRI were used as basic packages of the system, for the data topology and data analysis. The possibility for a direct input of the 3D geometrical data, the thematic characteristics as attributes of

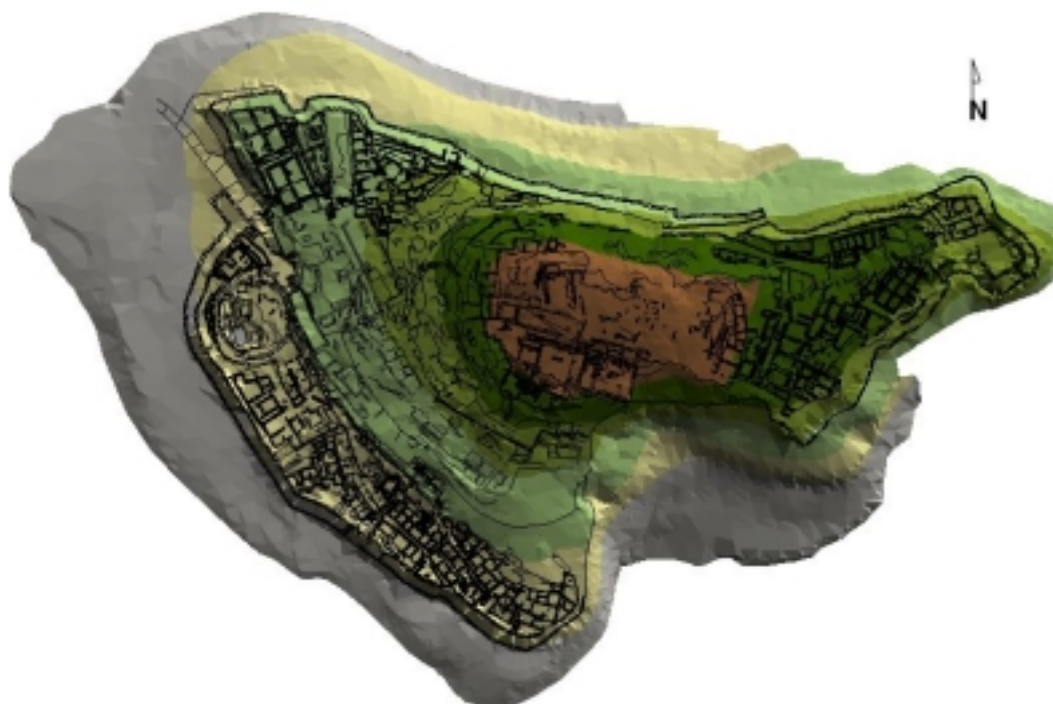


Figure 3. 2D-plotting of the surface model and the basic elements of the planimetry of the Acropolis



the polygons and lines, and the connection of photos in particular locations, has enabled the quick transfer of all data into the environment of the IS. The combination of CAD software and SIS has allowed the improvement of the process by making appropriate use of the advantages of each working environment. Figure 3. shows the geometric product of this combination in a 2D plan of the Acropolis and the surrounding area. The terrain is presented by selected leveling zones.

The data-attributes contained at the Data Base of the IS for each geometric element of the site, are: height, type, codification of its construction phase (for the construction elements), characteristic name-annotation of the area in which it belongs and special archaeological or architectural details related to that.

The generation of the 3D model was the basic operation of the module of SIS which refers to the data manipulation. The main factors for the selection of the particular compilation procedure are:

- the extensive area of the Acropolis, which really demands the application of fully automated methods, such as for the generation of the DTM (Fritch et al 1992)
- the high degree of detail collection and the high accuracy demands, that the technical specifications of the project define, which for example prevent the application of structuring the 3D model fully automatically.

It is obvious that the efficiency of the automated methods that are based on multi-image coverage of the object (Pollefeys et al 1999) is limited due to the large number of monumental constructions that should be represented (both externally and internally –absence of any ceiling), even if a video instead of photos will be used. Also, the standardization of the 3D model for the constructions is impossible due to the complexity of the ruins and the monumental constructions on the Acropolis.

The selected solution was the creation of proper interfaces and specialized programs-scripts for a semi-automatic interactive process for the structuring of the individual elements of the 3D model. For this work the continuous communication of the SIS and CAD is necessary. In the SIS environment the geometric characteristics were classified (ground, lower and upper polygon / line / point of the wall and the constructions, water pipe, grave etc) and in the CAD environment the surfaces of the various elements above the ground surface were structured virtually. The final representation and the integrated structure of the whole model was done in the SIS and particularly at the module 3D-Analyst of ArcView.

## 5 DATA VISUALIZATION

The ways of presentation of the 3D model of our object constitute the last but not less important operation of the IS. Especially for the archaeological applications, various methods with more or less impressive products have been proposed and applied, such as the 3D textural scenes with draping of ortho- or rectified photos at the surface of the monument, animated fly-throughs, actual views from human viewpoints etc (selective references: Guerra et al 1999, Ito et al 1998 etc). The inherent tools of the commercial IS packages and specialized programs with VRML applications, that are connected with them, as well as the multimedia tools of hardware, provide immense capabilities.

At the particular project, the special modules of the previously applied software packages were used:

- the rendering operation, at the CAD environment
- the 3D scene modelling at the 3D-Analyst package, at the SIS environment.

The process of generating the 3D views is fully automated, presupposing that the structure of the 3D model of the site has been finished. The relevant operations are provided in special menus of the software packages. The procedure includes:

- recall of various levels of information with their geographic characteristics (geometry and attributes), such as the DTM as TIN or GRID type, the constructions at a 3D-wireframe representation etc
- definition of the parameters for the creation of the 3D scene, such as the attribute that will be shown at the third dimension (for this particular application the leveling), the units (capability in exaggeration at the third dimension), the colors and texture etc
- creating slope maps and other byproducts, such as visibility analysis
- determination of the location and the orientation of the light source and the observer.

Figures 4., 5. and 6. show some specific 3D representations of the Acropolis of Mycenae from various points of view, having the light source at the eastern side, at an angle of 50° from the horizon. In Fig. 4 a total view of the western side of the archaeological site is shown. Other views can be derived also, containing some thematic information at the third dimension, i.e. construction phases or other archaeological information and finally a representation of the site as it was at a particular era in antiquity. Also, views as results of some queries to the SIS can be compiled.

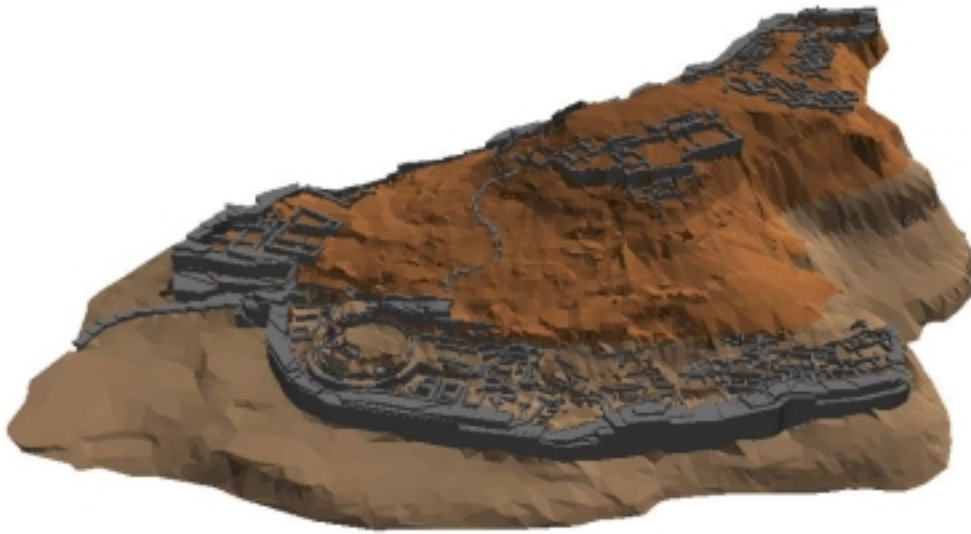


Figure 4. 3D western view of all the Acropolis of Mycenae

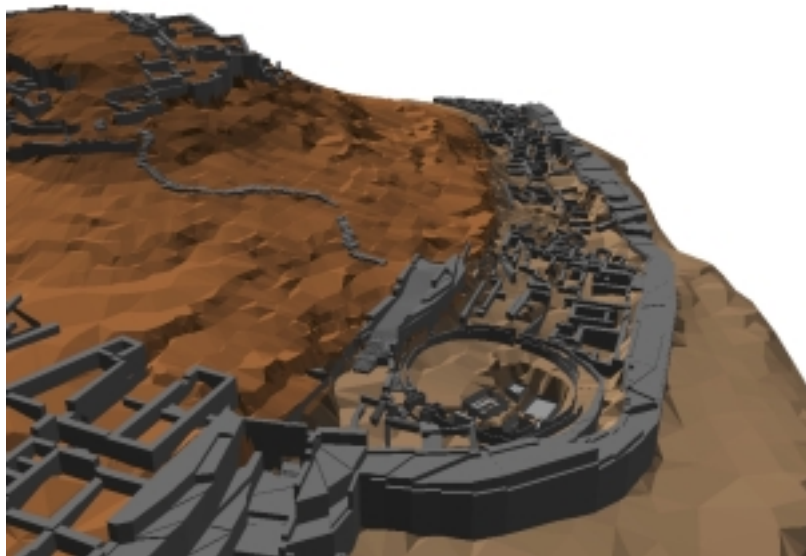


Figure 5. 3D detailed view of the Grave Circle

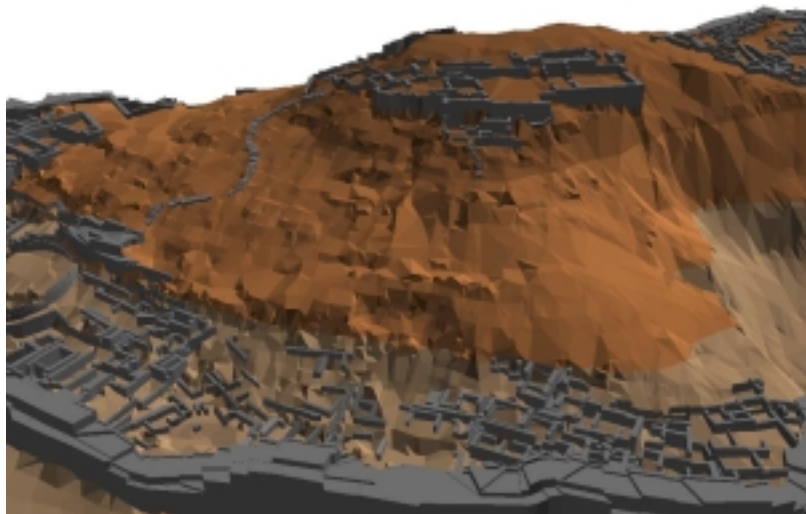


Figure 6. 3D detailed view of the southern part: the Sacred Centre is shown in front and the Palace in distance

## 6 CONCLUSIONS

The design and creation of a SIS for detailed documentation and 3D representation of the Acropolis of Mycenae, has shown not only the problems and restrictions, but also the existing possibilities for the application of such techniques in complicated archaeological sites. The application of automated methods to the compilation of the geometric data and to the modelling of the site, faces great difficulties. Necessarily we have to use more time-consuming procedures.

Yet, the 3D representations (with or without raster data on the surface of the object) and the detailed 3D models constitute considerable tools for the study of the monuments. Photogrammetric techniques in combination with IS tools for 3D data management, fulfil these needs in the best way. There is still a great space for improvements and product developments that will embroad the application fields even more.

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