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The Acropolis Restoration News

10 • July 2010

PROCEEDINGS of a ONE-DAY CONFERENCE
Modern technologies in the restoration of the Acropolis
19 March 2010

Orthophotomosaic of the Acropolis rock. Study for the development of Geographical Information Systems on the Acropolis of Athens, 2009

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The conservation and restoration of historic monuments are, par excellence, a conservative activity of modern societies. Yet the means by which this is accomplished are, conversely, dynamic in character and continuously improve. For the monuments of the Acropolis, unique in their artistic and historical value, a result that was faithful to ancient ways of building was sought, but using all the means that would yield economy of power, security and speed in accomplishment.
As you will see, modern technology, as much in the accomplishment of the main work as in compliance with the actions required by existing ethic, is developing and contributing at unprecedented rates. I mean primarily in documentation and in the diagnosis of damage and alterations in the ancient monuments, but also in storing and disseminating information.
When the Committee for Conservation of the Acropolis Monuments (ESMA) began its work, 35 years ago, terrestrial photogrammetry was a recent invention and the Topography Centre of Saint Mandé, through the UNESCO, produced the first plans from the photogrammetric survey of the Acropolis, which were of little help to us. Few realised then that computers would dramatically change photogrammetry so that we have the wondrous achievements that you are about to see.
Digital technology has opened up new possibilities in documentation before the interventions, with orthophotographs and precision imaging, although it deprived us of the parallel, diagnostic examination that occurred during traditional surveying. Yet for great size, as, for example, the circuit Walls of the Acropolis, it is advantageous in that it provides precise measurements, necessary for the diagnosis of damage or micro-movements and then for the composing of reliable studies. The transparency of all the activities of the Acropolis Restoration Service (YSMA) is considered our basic obligation. Digital technology has given this tremendous power in ranging world-wide through the Internet.
Before concluding I want to thank all the participants in today's conference and especially the Director of the Service, Ms. Maria Ioannidou, who in addition to multiple other tasks, had the initiative and care of its organisation. I thank as well all the speakers, and all of you who came to this event. Finally, I give my warm thanks to the Administrative Council of the Acropolis Museum for lending us the hall in which the present meeting is being held.

Poster for the conference "Modern technologies in the restoration of the Acropolis". Editing: P. Psaltis-P. Konstantopoulos

Professor Emeritus
Charalambos Bouras
President of the ESMA

Details of orthophotographs of the NW corner of the Parthenon (east view of the pedimental sima with the lion head, northwest metope, edge of the pedimental sima with the lion head viewed from above). Photo D. Mavromati, 2010

Imbued with a message from the past, the historic monuments of generations of people remain to the present day as living witnesses of their age-old traditions. People are becoming more and more conscious of the unity of human values and regard ancient monuments as a common heritage. The common responsibility to safeguard them for future generations is recognized. It is our duty to hand them on in the full richness of their authenticity.

With this statement in the introduction to the Charter of Venice, the first internationally accepted theoretical framework of principles for interventions on the monuments, the significance given by contemporary culture to the restoration of monuments is recorded. Architectural heritage, apart from its inestimable cultural value, shares in forming the consciousness of a common history and culture of all Europeans and in the establishment of an awareness that its protection requires the responsibility and collaboration of all the citizens.

In this framework, the funding of the works of restoration and promotion of the monuments of European culture by the European Union assumes special significance. The primary concern is to repair the damage the monuments have suffered, to ensure the authenticity of their structure and form and to display the historical and artistic values they embody.

Included among the principles of the Charter of Venice, which directly reflects the main perceptions of its time, is the use of contemporary technology for restoring the monuments together with traditional techniques and methods. In recent years, new perceptions stemming from globalisation require the use of modern technology for the protection of the monuments. Advanced technology is utilised more and more during the research and performance phase of the programme of protection. Likewise in the phase in which an increase in the monuments' comprehensibility and educational influence are sought, in accordance with the social demands of the present period for better understanding, enjoyment and sharing in cultural heritage.

The use of advanced technology both in carrying out the studies and research, and in the execution of the works, has been a basic characteristic of the interventions on the Acropolis monuments, from their very beginning in 1975 by the ESMA. Particularly after 2000, after the establishment of the YSMA and the beginning of an extensive restoration programme on the monuments, advanced technology supported the development and acceleration of the Acropolis works and led to innovative scholarly and technical methods and to technological applications.

Fig. 1. Photographing of the south Wall of the Acropolis with balloon. Photo V. Manidaki, 2008

Specifically, advanced technology has contributed to:

• The restoration of areas of the monuments restored in the past and in the creation of architectural members from fragments that belong together.

• Research on the stability of the monuments and their structural restoration using advanced scientific methods, and the forming of a related digital methodology.

• Monitoring the natural and mechanical properties of the building materials of the monuments, as well as the materials used in the anastelosis.

• The development of innovative applications during the course of the works. As characteristic examples we should mention the restoration of columns of the Parthenon opisthonaos in situ and the cleaning of the surfaces of the Parthenon west frieze blocks with an original laser system.

• The development of important technical knowledge about hoisting systems that are used in restoration and innovative constructions for accelerating the works. Characteristic examples are the suspension grapple for architectural members, the tables for making joins, the special pantographs and the original machine for cutting the flutes of the column drums from new marble.

• The creation of a digital database for the management and direct use of the systematic documentation of the interventions.

These applications are more or less well known, since they have been presented in the past. An objective of the one-day conference is to present the YSMA's more recent activities in the application of today's technology. These activities had three aims:

1. The documentation and graphic mapping of the monuments, the circuit Walls and the rock.

2. The instrumental monitoring and recording of the structural behaviour, of deformations and minor movements, as well as seismic load on the monuments.

3. Informing and promoting the works of restoration on the Acropolis for the scholarly world and general public.

Geometric documentation is the first step in the restoration of a monument. What is of particular interest is the recording and mapping of the changes in the original geometry of the monument and the damages it has suffered. These features, in connection with the study of the historical and archaeological evidence and the structural pathology of the monument, form the necessary infrastructure for its restoration. In the case of the Acropolis, from 1975 on, the possibilities offered by the use of conventional methods and instruments were employed for surveying the monuments. These surveys enabled us to produce drawings of high aesthetic quality and accuracy, and they formed the basis for the interventions that have been carried out until today. For the Acropolis hill and the circuit Walls in particular, however, conventional methods could not yield reliable results. The main reason was the great size of the monument, the difficulty of reaching certain of its areas, its strong relief and the continuous presence of visitors in the archaeological site. Very early an attempt was made to utilise photogrammetry, the science that uses information about natural objects and the environment that come from the procedure of recording, measuring and interpreting photographic images. The need for surveying the Walls and the rock with the photogrammetric method was already noted in the first meeting of the ESMA on 25.2.1975 and the subject arose frequently in the discussions of the Committee. Although this method is one of the fastest topographical means of geometric documentation, results in the past were not especially successful in the surveying of monuments. This was mainly because of the difficulty of rendering the special forms and features of the targets, but also because the topographer who was applying the method had to be familiar with ancient architecture.

The application during the past years of digital techniques to photogrammetry, and the specialising of topographer engineers in issues concerning the monuments, has made it possible to produce orthophotomosaics and three-dimensional models with texture of high quality and precision. With correct processing and composition of significant numbers of photographs, this method allows the production of orthophotomosaics that combine geometrical accuracy of the plan with the optical - quality information of the photograph. Given these possibilities the YSMA decided to make use of the results of photogrammetry with funding from the "Information Society" (IS). We should emphasise here the assistance of the YSMA archaeologist Ms. Dorina Moullou, who worked on the investigation of all the existing possibilities for completing the work, preparing the proposal to the "Information Society" and composing the study for designing the work. She also collaborated energetically and determinatively in the many meetings with Ms. Tsigani, the Head of the Project Monitoring for the works of the Operational Programme "Digital Convergence". Invaluable likewise was the contribution of Ms. Dionysia Mavromati, rural and surving engineer specialising in photogrammetry, employee in 2006 of the Ministry of Culture's Directorate of Topography, Photogrammetry and Land Register and, from November 2007, employee of the YSMA. Ms. Mavromati played an active part in the entire process of preparing the announcement and the proceedings of the competition. The YSMA proposal, entitled "Development of Geographical Information Systems at the Acropolis of Athens" and the budget of €765,348.50 was approved in June 2006.

Fig. 2. Orthophotomosaic of the Acropolis rock. Study for the development of GIS on the Acropolis of Athens, 2009

The work included, in the end, the following sub-projects:

1. Supply-Installation of Equipment and Basic Information Software - Wireless Network, Topographical Geodetic Station, Operating Services of the Topographical Station, with a budget of €239,606.50.

2. Study for the Development of Geographical Information Systems on the Acropolis of Athens, with a budget of €380,800.

3. Archaeological Documentation Services, with a budget of €144,942.

On the contents of the sub-projects, you will be addressed by their contributors themselves. Here we list some of the features of the 2nd sub-project, which is the largest in scope of similar applications internationally.

After an international competition, the sub-project was undertaken by the Consortium "Elpho - Geotech". Taking part also were the Elpho Ltd., Geotech Partners, the National Research Council of Canada (NRC), the Institute of Mediterranean Studies of the Foundation of Research and Technology of Crete and the Swiss Federal Institute of Technology (ETHZ) of Zurich. Supervision of the work was undertaken by Ms. D. Mavromati and Ms. D. Moullou, to the end of June 2009, when the contract of the latter with the YSMA ended.

The main goals of the sub-project were:

1. Establishment of single geodetic networks.

2. Mapping of the relief of the Acropolis with full topographical and photogrammetric survey of the Walls (at scales of 1:50 and 1:25) and of the plan of the Acropolis (at a scale of 1:100).

3. Three-dimensional scanning of the Erechtheion and the circuit Walls for their full length, interior and exterior.

4. Development of a flexible Geographical

Fig. 3. Orthophotomosaic of the Archaios Naos. Study for the development of GIS on the Acropolis of Athens, 2009

Information System (GIS), together with the up-grading of the existing database of the anastelosis interventions, for managing all the databases.

5. Export of all the data to the Internet.

The execution of the work presented peculiarities and problems that were resolved, thanks to the excellent collaboration of the supervisors with those studying the work. Before beginning the work, the rock and Walls were cleared of flora by specialised climbers. There was particular difficulty in taking photographs on the Acropolis using the special balloon, since it was the only means permitted and it had to be replaced three times. The success of the photogrammetric plotting is due, to a great extent, to the continuous monitoring and corrections of what is to be delivered in stages, by Ms. D. Mavromati, whose familiarity with the monuments has enabled her to recognise immediately all the uncertainties in the rendition of details, so as to indicate their correction.

Those carrying out the work develop the separate parts of the sub-project as follows:

• Ms. D. Mavromati discusses the problems of photogrammetric plotting of the monuments.

• For the Consortium, Mr. V. Tsingas, Mr. Ch. Liapakis and Mr. A. Grammatikopoulos discuss the photogrammetric plotting and three-dimensional scanning of the circuit Walls and the Erechtheion.

• Mr. Y. Alexopoulos, Information Technologist of the YSMA Documentation Office, presents the upgrading of the YSMA documentation database.

• The YSMA architects Ms. V. Eleftheriou and Ms. V. Manidaki discuss the use of photogrammetry as a tool in architectural research.

The second unit of the one-day conference is dedicated to the monitoring with instruments and recording of the structural behaviour, the deformations, minor movements, as well as the effects of seismic activity on the monuments. All the activities next to be described were funded by the programme "Culture" of the 3rd Community Support Framework.

The monuments of the Acropolis have been subjected, through the ages, to much strain and the parts still standing have reacted satisfactorily. The geometric deformations, the movements and the damage the buildings have suffered are the evidence of their long-term behaviour under load, something that does not hold for more recent buildings. Thus, it is of great importance to plot the damage and diagnose the causes, a process that in itself contributes to the recognition of the problems of building and anti-seismic planning in the interventions.

Of special interest is the study of the problems of the Acropolis circuit Walls, a monument of exceptional importance. The continuous repairs from antiquity to today have contributed to their survival. Even so, structural damage, such as cracks, gaps and severe deformations, is apparent in many areas of the ancient construction as well as in the parts comprising later repairs. The programme that is today in full development concerns the systematic monitoring of the Wall, in order to research its static efficiency, compile studies and carry out interventions on it of a rescue nature.

Among the applications of recent years, the most important are:

• Geophysical prospection: electrical tomography was carried out in order to determine the contours of the south side of the Wall. It was not possible to determine precise geometric contours, but areas with a high amount of dampness were located.

• Installation of a network of seven accelerographs at specific points of the rock and the Parthenon. The purpose of developing this network, being carried out in collaboration with the Geodynamic Institute of the National Observatory of Athens, is to record seismic action and the response of the hill and the monuments to these. Already recorded are the seismic movements of the rock as a result of the earthquake of Andravidha (8.6.2008), with greatest acceleration 6mg, and the earthquake of Mandoudhi (14.10.2008) with greatest acceleration 4mg. These are the first recordings of seismic action on the sacred rock. Mr. I. Kalogeras, on the part of the Geodynamic Institute, presents the programme and the difficulties in its realisation.

• Installation of a system of optical fibres with sensors to detect deformations, temperature and pressure at specific points on

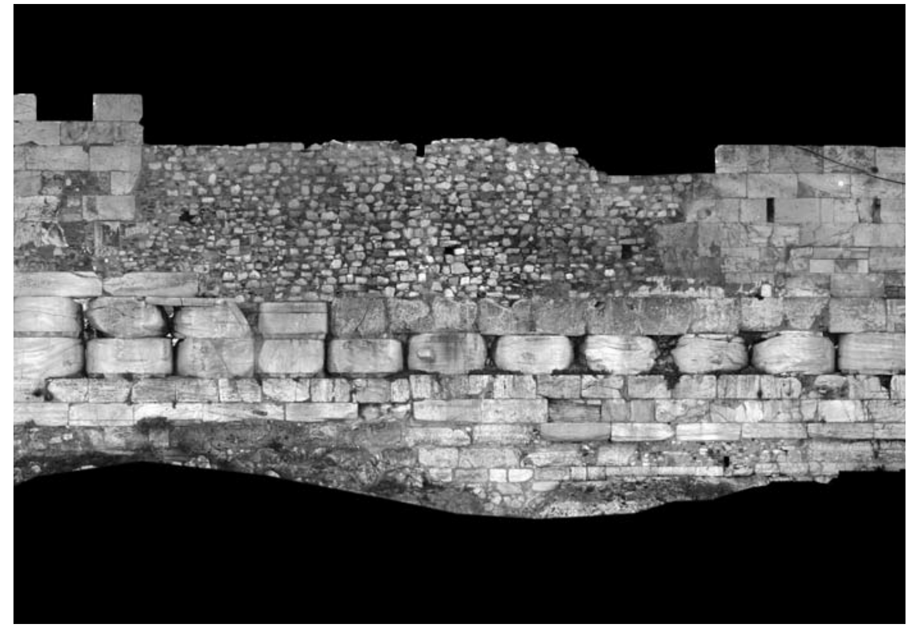

Fig. 4. Orthophotomosaic of the north Wall of the Acropolis. Study for the development of GIS on the Acropolis of Athens, 2009

the circuit Wall and the monuments. Mr. V. Astreinidis, outside collaborator of the Service, and Mr. D. Egglezos, present this application.

• Highly accurate measurements of topographical targets on the Wall. The measurements are for the purpose of monitoring micro-movements at specific points of the Wall with a topographical instrument of high accuracy. The application is presented by the YSMA architect Ms. V. Manidaki together with the Service's outside colleagues Mr. Th. Iliopoulos, S. Leloudas and I. Partsinevelos.

• The geotechnical engineer Mr. D. Egglezos, employee of the YSMA until the end of June 2009, will present the application of the data recorded in the studies for consolidation of the circuit Walls.

Finally, we must report the recent activities of the YSMA that are intended to inform the scholarly world and the general public about the monuments and the works of restoration. The "Digital activities of the YSMA", with a budget of €500,000 comprise a sub-project of the work "Digitisation and digital documentation of all the monuments of the Ministry of Culture" and they include:

• The creation of a "Virtual Theatre" in the new Acropolis Museum. Shown in this hall will be stereoscopic and simple projections of films about the history of the anastelosis of the four great monuments of the Acropolis.

• Reforming the YSMA website.

• Digitisation of the ESMA archive in order to create an electronical library (e-library).

• Creation of a system of electronical education (e-learning).

• Production of films with three-dimensional graphics. The YSMA has already made three films entitled "The Acropolis in Antiquity", "Building an ancient temple" and "The restoration of the Erechtheion".

• The installation of electronical information stations (infokiosks) on the Acropolis.

With the completion of the great restoration programme that was launched in 2000, a creative period of the Acropolis restorations will come to an end; another era will begin. Programmed for the coming years are interventions in other parts of the monuments that show structural problems. It is my belief that in the new phase of the works, the driving forces will be the knowledge and experience gained in the preceding years, together with the creative spirit and enthusiasm that has characterised the period that has ended. In this way we will be able to see the monuments of the Acropolis restored, not only as symbols through the ages of the classical Greek spirit, but as evidence of the scholarly and technical knowledge of contemporary Greece as well.

Fig. 5. Section of an orthophotomosaic showing the plan of the Parthenon (west side). Study for the development of GIS on the Acropolis of Athens, 2009

Maria Ioannidou
Civil Engineer
Director of the YSMA

Introduction

The limited use of both digital geographic data and Geographical Information Systems (GIS) in Public Administration to support planning and decision making, is an essential factor in slowing development and, simultaneously, weakening the provision of high level services. The present introduction will describe the methodology followed by the Operational Programme "Information Society" (OPIS), the aim of which is the appropriate distribution of available funds for developing spatial data infrastructures together with accompanying GIS applications.

The Operational Programme "Information Society" (OPIS) and the Digital Convergence Programme

The Operational Programme "Information Society" (OPIS), unlike the other Sectoral and Regional Operational Programmes funded by the 3rd Community Support Framework, is an innovative and multisectoral horizontal programme that penetrates all sections of development at all administrative levels. It has been designed so as to have strong regional dimension and most of its actions are nationwide:

• With local services (Citizen Support Centers).

• With financial assistance for small and medium enterprises in order to digitise the way they function.

• With training programmes for the unemployed and training of educators in information and communication technologies (ITC).

• With the establishment of public services with panhelladic access through the Internet (Tax declaration, Property Registry, Cadastre, Social Security Registry).

• By establishing the Public Administration Telecommunication Networks and Integrated Management Information Systems in each of 13 Regions and 52 Prefectures.

• With the creation of more than 3500 informatics laboratories for all levels of education and improvement of the school telecom networks.

• Broadband infrastructure and services.

• National Geographical Information Infrastructure and GIS applications at local, regional and national level.

For the forthcoming programming period, the Operational Programme "Digital Convergence" will also fund activities that will strengthen the National Spatial Data Infrastructure based on the annexes of "INSPIRE" EU Directive, as these are gradually issued. At the same time the applications of those involved will be reinforced, on the basis of interoperability of the data.

What are the GIS?

The elements that describe the sum of the properties or characteristics of an entity of the natural or manmade environment comprise descriptive information. For example the characterization of a monument as "Byzantine" describes the time during which the building was constructed. Yet that information by itself, even though it can define a feature of the monument, gives it no spatial dimension. On the other hand, a map of Greece on which the monument is placed in Thessaloniki, is a valuable datum. The combination of the spatial with the descriptive information of an entity and of course with the use of ICT constitutes a Geographical Information System (GIS).

Many features are combined to make a GIS effective and functional. The most basic of all is correct project designing. Great emphasis must be placed:

• on accuracy in the result through correct standards,

• on the source of the data (choice of primary or secondary data),

• on the designing of the geospatial database – on the basis of description data, spatial data, accuracy, clarity, information, historicity, compatibility.

The advantages of the GIS are many compared to the simple information systems or automated mapping, but this is not a topic of this presentation. The only point worth mentioning here is that those systems form a powerful tool for decision-making. This by itself is a revolution in the way Public Administration operates.

National Infrastructure of Spatial Data

Purpose and Configuration of Function of the National Infrastructure of Spatial Data

The National Infrastructure will include all the necessary actions, both on the organising and technological level, so as to adapt the wider Public Administration to the directions of the European Union in respect to the methods of organisation and provision of geographical information to the Internet (INSPIRE). The purpose is the development of a fully functional and productive system for providing geographical and thematic information on the Internet. The system will offer electronic services to citizens, businesses, and to the Public Administration as a whole.

At present, except for the expressed desire on the part of some intermediaries to support the installation of a National Spatial Data Infrastructure, there is no coordination at all. There are no common norms that can be used, and interoperability between data agents, even between services of the same agent, is totally impossible. At the same time, the European status is being formed and is based mainly on the completion of national infrastructures. The fact that already in Greece numerous projects are being carried out that have to do with Geographical Information Systems makes their coordination and the harmonisation of their results urgent, so that the geographical data produced can be entered in a completed information system, be reused and contribute to the National Geographical Data Infrastructure from a distance.

With the use of a Greek spatial data infrastructure (NSDI) the following aims will be achieved:

1. There will be a whole made up of single standards for adoption by the users for harmonising and conveying their data.

2. Location and access to users' data will be possible through the portal of the National Spatial Data Infrastructure and their subsequent unification will be to the advantage of every user.

3. It will be possible to enter other data and services in the National Spatial Data Infrastructure from any activity of geoinformation in the country.

4. There will be harmonising with international and european standards, such as INSPIRE.

Functional Requirements of the National Spatial Data Infrastructure

In general the National Spatial Data Infrastructure should support three basic user actions:

• The finding of geographical resources.

• The utilisation of available geographic resources.

• The use of appropriate resources.

Framework of Development and Functionality of the National Spatial Data Infrastructure

The framework of development of the National Spatial Data Infrastructure will standardise the processes of harmonisation, determining the means of representation of the spatial, topological and time characteristics of the entities, their semantics, their metadata and the functions and/or services that affect them. It has to be designed in this way so as to ensure:

• that the spatial data will be stored, saved and accessible in their most appropriate form,

• that it will be possible to combine data from different sources all over Greece and to share them with many users and applications,

• that data on one degree of Public Administration will be accessible from all other (local, regional, national, european).

At the same time, for successful functioning, equally important is the development of standards for recording the metadata. In accordance with the norms of the INSPIRE EU Directive, there will be two types of metadata: metadata for geographical information and metadata for Spatial Data Services. The norms must determine type, contents and structure of the metadata in both the above categories. The following subjects have to be considered:

• Rules for creation, storing and accessing the metadata.

• Possibility of verification, quality and precision through the metadata.

• Support of more languages and interoperability (for connection with INSPIRE or other international spatial infrastructures).

• Compatibility with european and international norms.

Current status in Greece

Until about six years ago, given the lack of a complete national or european framework for a single spatial data infrastructure, there were no coordinated efforts in that direction. An additional factor to the lack of information and resources was the reluctance of users in the public sector to exchange spatial data with each other, which they

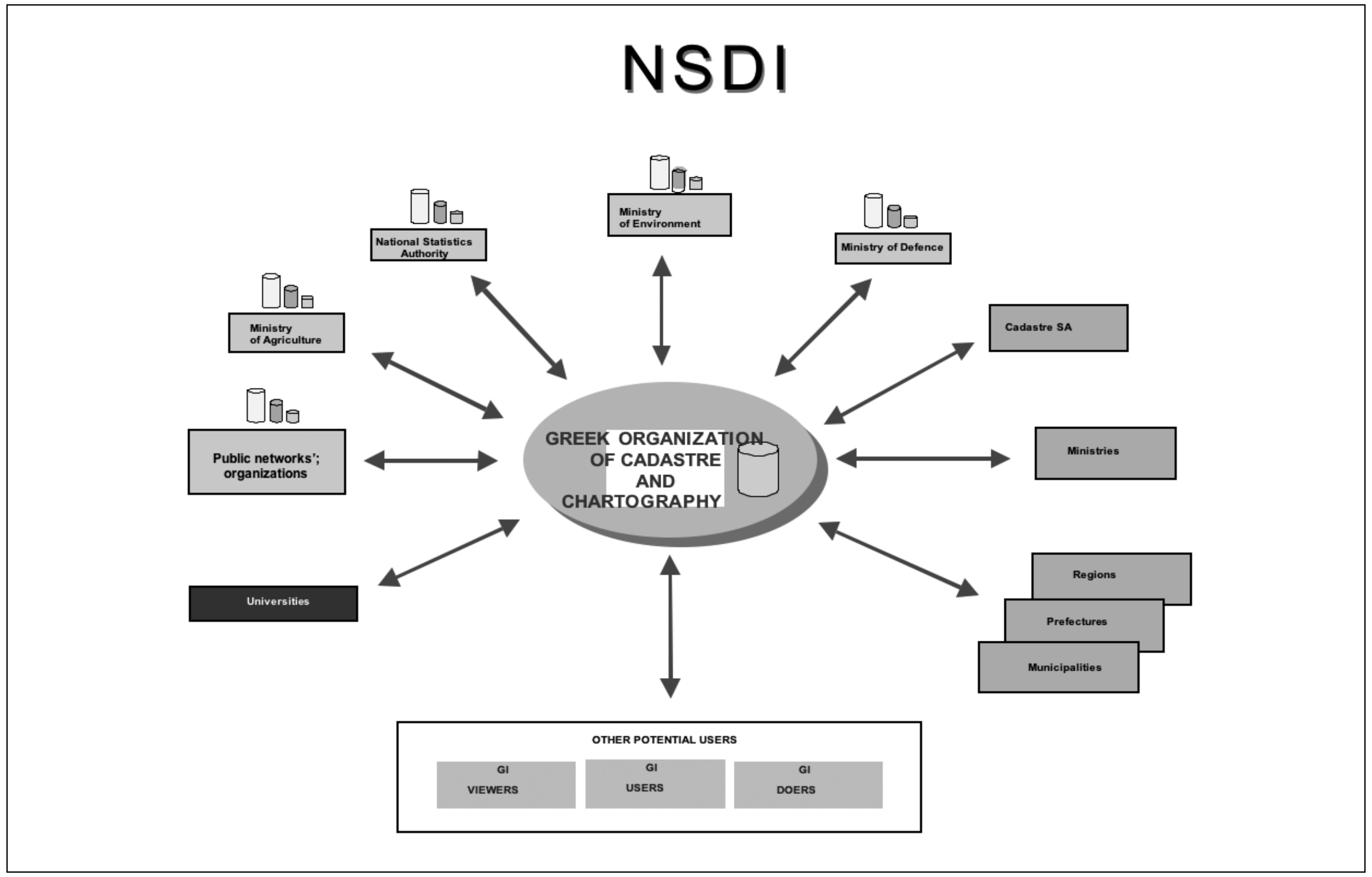

Diagram 1. Participators in the National Spatial Data Infrastructure

considered as the personal property of each user rather than property of the state. Whatever efforts there were to digitise analogue data or to acquire digital data were fragmentary and without homogenous rules and specifications. The limited penetration of the Public Administration by new technology, which was hampered by the users, moved matters in this same direction. Among other things, it prevented the users from comprehending the possibilities offered by the use of spatial data through specialised software applications.
The above situation, however, through the gradual introduction of new technology into Public Administration, through information and by way of new funding tools through the EU, contributed to the incorporation, stage by stage, of actions that were to lead gradually to the establishment of spatial infrastructures.
The most coordinated effort in this direction came through the opportunity of projects being funded by the EU through the 3rd Community Support Framework and, specifically, by the Operational Programme "Information Society".

The aim of the –at that time– initiative INSPIRE was to become accessible and directly usable on a national level, with common access by the public to functional spatial information. A programme for capturing new spatial data was not launched, but the data that was already available was utilised so that the data could gradually be harmonised in the member states. Benefitting would be those who participated in the planning, application, monitoring and utilisation of the policies on a european, national and local level, either as public agents or as citizens, universities, private entities, etc. Thus it is connected with spatial data not only in the public sector, but it covers also actions that can be performed by evoking an information application, that is spatial data services.

The measure 2.4 "Regional geographic information systems and innovative actions" of the OP "Information Society", was planned on the basis of the directions e-Government and e-Europe of the international target for compiling the European Spatial Data Infrastructure (ESDI) and Global Spatial Data Infrastructure (GSDI), and also the initiative INSPIRE, from which emerged the analysis of the separate aims-actions.

The aims of the measure include, among other things, the following:
1. Creation of a National Digital Geographic Infrastructure, as a single standard construction for exchange of digital data. The action is horizontal, and refers to the creation of geographic databases for the entire country. The infrastructure will include the collection of already existing datasets, their completion and the production of new, Internet community, standards of performance and user collaboration, access mechanisms, and policy of availability of the products.
2. Development of GIS for covering specialised needs of the users on a regional-local level, so as to form spatial data services.

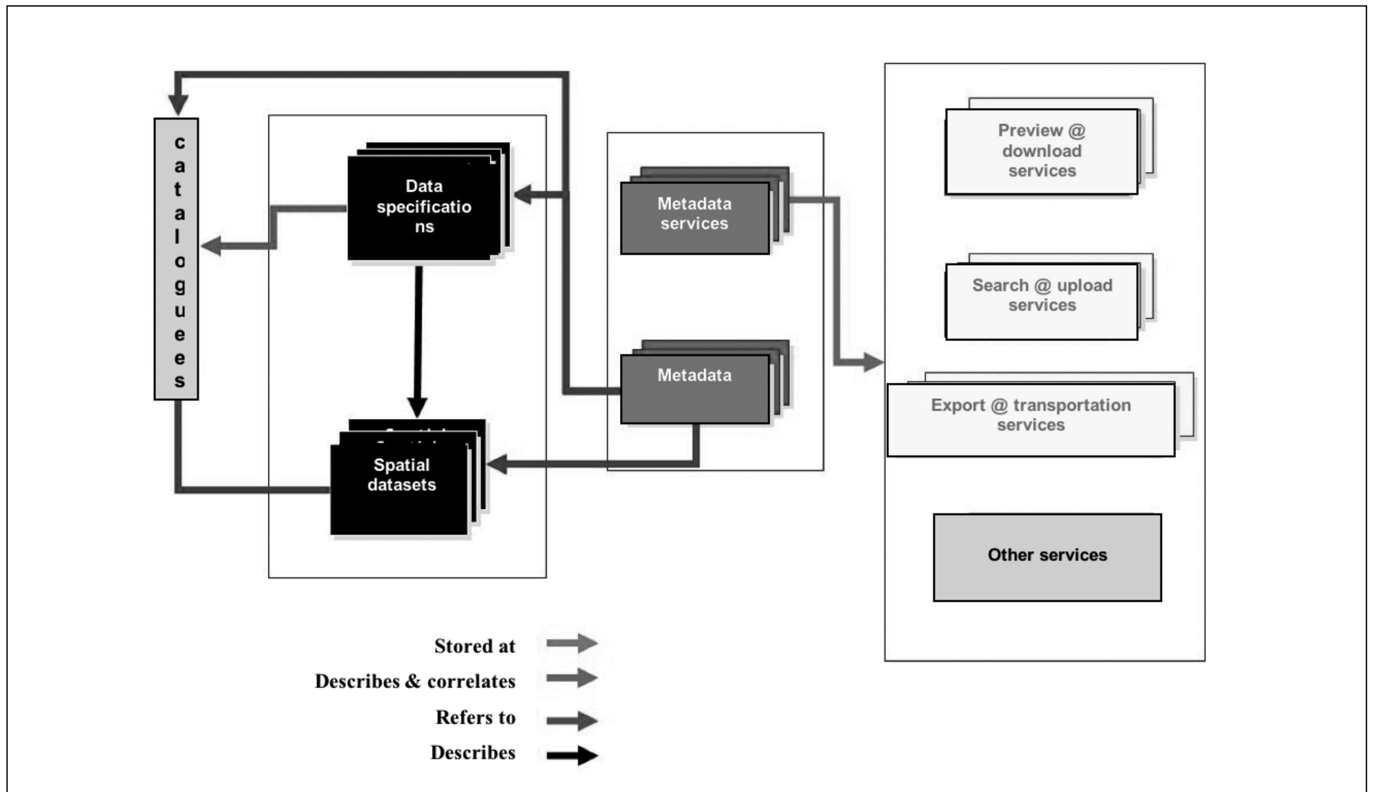

Diagram 2. Review of architectural model referring to the National Spatial Data Infrastructure

3. Development of GIS applications oriented to environmental themes.
The works were entered gradually, beginning with activities of national scope to the users who have the basic mass of spatial data in the country (Ministries). This was followed by works that produced new data and would develop specialised spatial data services.
It is worth noting that in all the integrated projects, there is as an obligation for participation-contribution to the National Spatial Data Infrastructure, when the State Coordinator is legally defined.

Basic national infrastructures in spatial data
• Greek Organization of Cadastre and Cartography: €4,200,000
Establishing a National Geographical Data Infrastructure.

• Ministry of Agricultural Development and Food: €6,000,000
Organisation and Dispense of Digital Geographic Data of the Agricultural Sector.

• Ministry of Defense - Army Ceographic Service: €4,500,000
Development of a Completed System for Business and the Dispensing of Geographical Data and the development of a Geographical Database of the Army Geographical Service.

• Ministry of the Environment, Physical Planning and Public Works: €4,500,000
Creation of a Digital Geographic Database, Creation of Metadata, Development of Business Sofware, Utilisation of a Network Node for Provision of Services and for helping the Citizen through the Internet and Electronical Networks.

• Ministry of the Environment, Physical Planning and Public Works - Directorate of Environmental Planning: €4,150,000
Updating and Extension of the National Network of Environmental Information.
In addition, all of the spatial data at national level supported by some of the actions of measure 2.9 of the same programme "Information technologies infrastructure and communications for a contemporary CADASTRE", raising the cost estimate for the integrated works to €108,868,240.11.

Specialised GIS applications
Information systems in the field of environment and transportation and GIS applications: €26,000,000.

Regions, Prefectures: information systems in the field of environment and transportation. Indicative actions: tele-monitoring for Protection of Forests from Fire, Networks of Combined Transportation, Transportation Networks.

Specialised GIS applications for Ministerial purposes. Indicative actions: GIS for Public Property, GPS for hydrographic data.

Digital City Planning: Geographical Information Systems for all Prefectures in Greece - Information Society SA, €12,500,000

Creation of GIS applications for the Municipalities in Greece: €15,000,000. Indicative actions: city planning applications, fleet management, digital city guide, parking management, greenery, municipal real estate, management of networks (water system, electricity, natural gas, transportation).

National Statistics Authority: Geoinformation Portal: €4,000,000

Ministry of Agricultural Development and Food: Digitisation of the declared farm plots of 2003 by producer: €2,647,940.51

Applications for the immediate solving of accessory problems, and also for the further protection of the environment so that in a short period of time presuppositions can be worked out for sustainable development in fire-stricken Prefectures: €21,000,000.
In terms of progress, most of the projects are completed.

Conclusions
The efforts to implement the projects that harmonise with the INSPIRE EU directive through the "Information Society" may not be the only ones, but they are the only ones that are coordinated, targeted and with a high budget allocated.
Implementation of these projects is expected to produce innovative procedures within the public sector, simplifying their functions by automating them and, through the systematic updating of their spatial data, improving at the same time the decision-making mechanisms. Thus the level of accomplishment, while simultaneously increasing their availability and usefulness to the citizen, on a regional and local level, will strengthen and promote the developmental character of Public Administration.
At the same time, the gradual introduction of corporate relations of Public Administration, Universities and the Private Sector will increase the availability of the data, reducing overlapping and improving function. The interoperability and gradual improvement in quality of the data, especially with the use of metadata, is expected to reduce substantially the cost of creating digital geographical information, accelerating economies of scale.
Finally, the technology transfer as well as the technical knowledge these projects will provide is expected to balance the management of digital spatial data on a national, inter-regional and regional-local level, thus contributing to a gradual understanding, both of the creation of a single infrastructure for spatial data and of the means of coordinating the actions this requires.

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Introduction

The project "Development of Geographical Information Systems on the Acropolis of Athens" (2007-2009) was designed to cover basic needs of the Acropolis Restoration Service (YSMA) in the sector of geographic documentation, to provide archaeological documentation services and to supply equipment and basic computer software, wireless networking and topographic monitoring of micro-movements with measurements of high accuracy (logistics) (fig.1).
Today, the project, with a budget of around €900,000, which was funded by Measure 2.4 of the Operational Programme "Information Society" (OPIS), has been finished; moreover within the time schedule and with great success as is shown by the results themselves, published analytically in the present fascicle (articles by Mavromati, Tsingas, Liapakis, Grammatikopoulos, Alexopoulos), and by the fact that many of these projects have already been used in works and studies connected mainly with the fortification Walls and the underlying rock of the Acropolis (article by Egglezos in the present fascicle).
In this article we shall not concentrate on the results, but on the designing and management implementation of the work, in an effort to show the reasons (administrative and scientific) that led the YSMA to certain specific choices.

History

In December 2004 the Committee for Conservation of the Acropolis Monuments (ESMA) entrusted the present author with the archaeological documentation of the fortification Walls. The main purpose was to record in this the ancient architectural members, fragments of sculpture and inscriptions that had been incorporated (ESMA decision no. 20/9.12.2004).
The need for this research had been recognised practically from the beginning of the ESMA anastelosis interventions. The scholarly personnel of the (then) Technical Office had worked on a series of relevant expositions pointing out the lack of existing data, the need for systematic documentation of the Walls and for programming an interdisciplinary approach to the problems [4]. Since the size of the monument and physical difficulties of approaching it made it impossible to carry out a study using the traditional method of inspection on the spot (fig. 2), the compilers of the study proposed a topographical and photogrammetric survey, methods which usually yield quick results. At the same time these methods are applied with non-contact techniques, so they are in accordance with the international charters of anastelosis interventions. Thus,

Fig. 1. Poster for the Operational Programme "Information Society"

at a very early stage, these methods were in use for surveying the archaeological areas and monuments. It is worth noting that the first photogrammetric survey was carried out in Persepolis in 1885 [3]. Photographic surveying has also been used on Greek monuments [1].
Unfortunately, in the case of the Acropolis monuments, the efforts to use these methods, for example on the Erechtheion (1977, photogrammetric line drawings –fig. 3– and initial rectified photomosaics) and on the south fortification Wall (2002, figurative final product-photomosaic, with planar rectification, which in the end was not completed) were not crowned with success [10]. This fact, together with the preference that had to be given to rescue operations on other monuments of the rock as well as the great expense of the entire operation, meant that a complete and exploitable photogrammetric study of the Wall could not be undertaken.
That geometric documentation of the monument was not undertaken led in fact to a fragmented approach to its problems, both from the archaeological and the anastelosis standpoint [4, 2].
Thus, when the present writer was charged with the above study, there was a notable lack of data (archaeological, historical, photographic, graphic, measurements) in both the Service archive and in the international and national bibliography that would have been helpful in the research.
The problem of actual approach to the exterior surfaces of the Wall, moreover, had not been solved, despite the supply and installation of a special suspended work-platform measuring 2x0.80m (installed in April 2005). This, however, provided access only to the south Wall, whereas it was not possible to retain it in many other places for more than two or three days, a length of time that was clearly insufficient for in situ recording and drawing of each discrete member in the area covered by the platform (fig. 4).
At the same time, it was not permissible to install scaffolding for economic and aesthetic reasons. The only alternative for carrying out inspection on the spot, mapping from the crown of the Wall, was not even discussed because of danger.
All this led to a review of a solution with photogrammetric plotting, since, as we have already noted, this method allows the desired data to be collected macroscopically and it ensures a quick rendition of the results, at least by comparison with the traditional method, which is particularly time consuming.
The hesitation of previous years about the use of photogrammetry, was put aside with the realisation that contemporary photogrammetric products (orthophotomosaics) could be combined with full three-dimensional scanning (3D models with texture). In this way the two methods of recording could supplement each other, while three-dimensional scanning was considered necessary for the geometric documentation of the rocky slope.
After this, the primer necessary to start a systematic effort to produce a total design for this project was the funding. By good fortune Measure 2.4 of the OP "Information Society" (hereafter IS), as it was organised under the decision of 8.12.2003 of the

Fig. 2. View of the south Wall of the Acropolis from the S. Photo S. Gesaphidis, 2009

3rd Monitoring Committee of the OPIS (see the relevant OPIS Supplement to the Programming - Technical Bulletin Measure 2.4) provided government agents with the possibility of developing Geographical Information Systems (GIS) for indicative purposes of critical situations, management, monitoring and protection of fragile areas. The YSMA thus had the opportunity to design a complete programme that would include topographical and photogrammetric recording of the Acropolis Walls and rock, the infrastructure for monitoring micro-movements in the Wall, its present condition, and enable it also to carry out and evaluate measures for its consolidation. With this, it was possible to design a database for the Walls, to update the existing database for the architectural members of the rest of the monuments and to connect them with GIS.

The designing

The ESMA and the YSMA, now having in mind the new situation and the likelihood of funding from the European Programmes, adopted the designing of a proposal to be submitted for approval to the Managing Authority of the OPIS, with the method of comparative evaluation.
The productive collaboration of the scholarly/scientific personnel of the YSMA, with the participation of M. Ioannidou (Civil Engineer, Director of the YSMA), F. Mallouchou-Tufano (PhD Archaeologist, then Head of the Documentation Office), V. Manidaki (Architect, then responsible for the restoration of the Circuit Walls) and Y. Alexopoulos (Informatics Specialist, in charge of Informatics), was the greatest contribution to the strategic planning and interdisciplinary approach to the problem.
Thus the study for planning the project "Development of Geographical Information Systems on the Acropolis of Athens" [8] was drawn up by the present writer, the main axes being:
1. Analysis of the existing data.
2. Recording of the problems.
3. Determination of needs.
4. Planning the aims of the programme.
5. Determination of steps needed to reach goals successfully.
6. Setting a realistic schedule for completing the programme.
7. Determination of costs.
8. The existing legal framework.
9. The guidelines of the European Union (for example e-Europe 2005, e-Government, WAI) and Measure 2.4. of the OPIS.
10. The feasibility of the work, that is its evaluation as to whether it is worthwhile utilising the programme, given the specified time and cost.
11. The durability of the work, that is, if and how the Service can support the work (added cost - benefit, cost of function/upkeep) after its completion [9].

Hence, the aim of the programme was the development of GIS in order to create the necessary mapping infrastructure and multilevel thematic maps, to provide information initially about the Walls and subsequently about the Acropolis monuments.
The following steps had first to be taken in order to reach the goals of the programme and to create the mapping infrastructure:
1. Upgrading of the existing database and creation of a new one for the Walls.
2. Establishment of the required new topographical networks and entry of both the existing and the new networks into a single reference system (Hellenic Geodetic System of Reference HGSR 87).
3. Production of orthophotomosaic for the Wall and for the plan of the Acropolis hill.
4. Three-dimensional scanning of the Wall and the rock, also of the Erechtheion, the only monument up to then with the work of anastelosis completed.
5. Establishment of a topographical infra-

structure system for monitoring the micro-movements and deformations of the Walls.
6. Supply of equipment and basic computer software and wireless networking in order to establish the basic infrastructures for its function and conservation.
7. Instruction of YSMA personnel in the technological applications that would be developed in the context of the programme.
8. Provision of archaeological documentation services for entering information in the database of the Service.

The cost of all these actions, on the basis of continuous market research, came to €885, 390.00 and the time required for carrying out the work was determined at 18 months.

Solved through this programme were a number of time-consuming problems connected with the repair of the circuit Walls. Examples are the full and analytical geometric documentation of the monument and the underlying rock, the creation of an infrastructure for the architectural and archaeological documentation (of the building - historical phases and for recording the incorporated members), research on the pathology, and the static and seismic behaviour of the Walls. At the same time, the development of the database and installation of the GIS would facilitate the management of every type of information about the work of anastelosis.

The request and design study for entry of the programme in the OPIS were submitted after its approval by the ESMA in September 2005 (ESMA decision 10/19.9. 2005), in the context of call 142 of Measure 2.4. of the OPIS. The positive results for the Service were issued in May 2006, after two phases of evaluation. The good ranking of the proposal (3rd out of a total of 32 finally approved and many more rejected) meant the approval of the entire amount requested.

The implementation

After the funding was approved, the YSMA had immediately to take the next step, creation of a file of the work and announcement of an international competition, in accordance with the existing legal framework. The great experience of the YSMA in handling European funds, in conducting international competitions, in contracting and supervising technical works, facilitated the managerial aspect of the works. Even so, despite being staffed with a highly competent scholarly personnel, the lack of a specialist in the subject, that is a topographer specialising also in photogrammetry, had to be covered. For this reason the YSMA asked for assistance from the relevant service of the Ministry of Culture (now also of Tourism), the Directorate of Topography, Photogrammetry and Land Register, which is staffed with specialised scientific personnel, and in the past had satisfactorily carried out similar programmes. The Director of the Service, A. Kambourakis, responded immediately to the YSMA's request for collaboration and entrusted the matter to the Rural and Surveing Engineer of his service, D. Mavromati, a specialist in photogrammetry [5, 6].

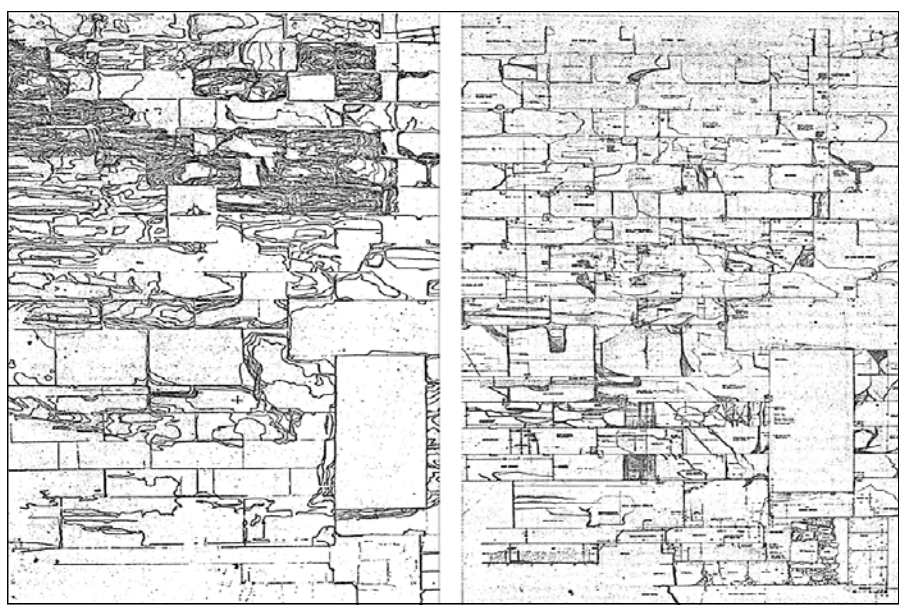

Fig. 3. Erechtheion, south wall. Left, photogrammetric line drawing, not processed by an architect (Photogrammetry Laboratory of the National Technical University of Athens). Right, line drawing of same area, based on the photogrammetric survey, completed by an architect with field observations (Plotting-drawing: E. Moutopoulos)

With the collaboration of M. Ioannidou, D. Mavromati, Y. Alexopoulos, P. Katsimichas (head of the Accounting Office), V. Manidaki, D. Egglezos (PhD Civil Engineer-Soil Engineer, in charge of the work on the circuit Walls), S. Oikonomopoulos (Electrical Mechanical Engineer, in charge of the electromechanical team), A. Frangiadis (PhD Economist, outside collaborator of the YSMA) and the present writer, the separate parts of the work were determined and entrusted to the specialists in the material. Following this, the assignations were determined specifically, the problems that would probably emerge were noted [10], the technical requirements were compiled for each part of the work and a complete file was prepared.
On the basis of the above and in accordance with the existing legal framework (particularly Law 3316/2005), the work was divided initially into two and later (after the competition was held and the work assigned to the contractors) into three sub-projects:
1. "Study for the Development of Geographical Information Systems on the Acropolis of Athens". It included the geodetic and photogrammetric works (orthophotomosaics and three-dimensional scanning), the creation of a database for the Wall, the updating of the existing database and the development of GIS. The contractor was the Consortium "Elpho - Geotech". Participating in addition to these two companies were the National Research Council (NRC) of Canada, the Institute of Mediterranean Studies (IMS) of the Foundation of Research and Technology of Crete (FORTH) and the Swiss Federal Institute of Technology (ETHZ). D. Mavromati and the undersigned assumed supervision of the work.

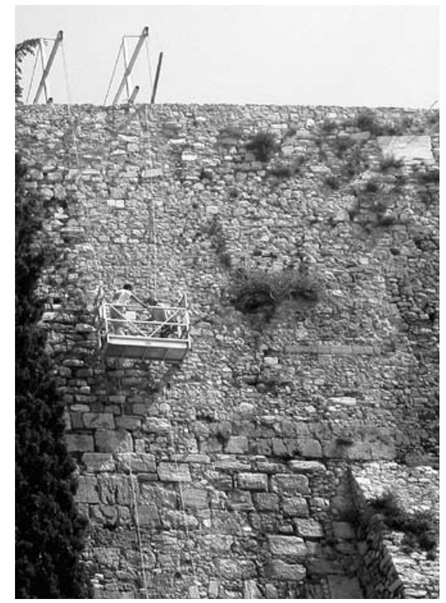

Fig. 4. Work platform at the south Wall. Photo V. Manidaki, 2005

2. "Supply and Installation of the Equipment and Provision of Services for the Development of Software Applications", the object being to supply and install specialised information equipment, wireless networking, a topographical geodetic station, and the relevant software for making processing possible, management and updating of information about the Walls and the other monuments of the Acropolis. Contractor for the work was the company Epafos Information Systems Ltd. Y. Alexopoulos was in charge.
3. "Archaeological Documentation Services", with the objective of supplying digitisation services, archaeological documentation and content importation. Contractor was the Institute of Mediterranean Studies (IMS) of the Technology and Research Foundation of Crete (FORTH). Dr. F. Mallouchou-Tufano was in charge.

Results

The successful completion of this work, especially necessary from the standpoint of size as well as scholarly and managerial complexity, would not have been possible without the creative collaboration of scholars from different fields of knowledge. It is clear that the effort to record and confront the problems of the monuments, from whatever angle they may be viewed, requires systematic preparation, interdisciplinary research and lengthy collective effort. The designing of the work, based on a specific plan, with the active collaboration of all the relevant specialities and interdisciplinary monitoring throughout its course, ensures its success, which depends directly on the final results being utilised. Through this particular work, moreover, it emerged that collaboration between the various Services of the Ministry can be of great value.

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Geometric documentation forms the necessary basis for any study in the field of restoring monuments. The importation of digital techniques into photogrammetry during recent years has introduced important changes in the final results and it has led to the gradual replacement of line drawings with raster products combining the geometric accuracy of the line drawings with the optical-quality information of the photograph, that is, orthophotomosaics and three-dimensional models with texture. These products comprise today the typical photogrammetric deliverables, especially for the documentation of archaeological sites and monuments.

Compared to the production of the orthophotomaps that are used as a basis, for example in land register studies or road planning, orthoimaging for purposes of archaeological documentation has significant peculiarities and difficulties. To begin with, the shape of the archaeological objects is usually complex and characterised by irregular changes in relief, sharp discontinuities, recesses and strongly protruding areas. Large parts of a monument are likely to be covered by scaffolding, especially if the documentation is carried out at different phases of its restoration. An archaeological site, moreover, may be located in a thickly settled area or it may be difficult to approach. Furthermore, quite apart from the size of the object to be recorded, the scale required in archaeological documentation is large. The usual scales are 1:10, 1:20 and 1:50. As a result, the final raster product, aside from geometric accuracy, requires corresponding optical quality so that the final recipient can make use of it.

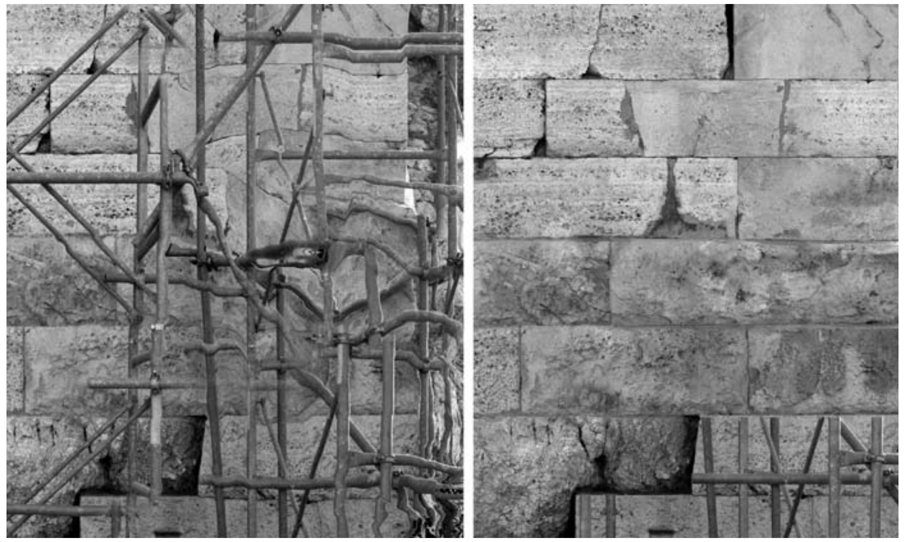

Fig. 2. Tower of the temple of Athena Nike. Deformed orthophotograph (left). Final orthophotograph (right)

All the above substantially affect the image acquisition. In archaeological documentation the camera elevators (platforms) must be suitable for both horizontal and vertical photography, and cover a wide range of imaging distances. Two solutions for raising the camera that have been used successfully by the Directorate of Topographical Photogrammetry and Land Register of the Ministry of Culture and Tourism are a) a helium balloon 2m in diameter and b) a suitably constructed telescopic pole. It should be noted that no type of engine-propelled aircraft or helicopter is allowed to fly over the Acropolis rock at an altitude of less than 5,000 feet, and for jet aircraft 10,000 feet.

The use of an unstable platform such as the helium balloon, even though it can be connected with a computer screen, does not allow full control of the image acquisition. The result is irregular geometry of the block configuration. Images of different scales often emerge, something which is exacerbated by the strong relief of the surface. The tilts of the image, in both horizontal and vertical photography, around the vertical axis are significant: they can exceed 15° with the result that the overlap differs from that originally programmed (fig. 1). The different scale of the adjacent images, the coverage that is not fully controlled and the notable image tilts directly affect phototriangulation.

In order to meet the predetermined accuracy of the phototriangulation, dense recording is needed to ensure adequate overlap and number of intersecting rays. This is in any case necessary so as to ensure that no areas are "hidden" because of perspective. It is likewise important to have a large number of ground control points and tie points, which must be measured to the extent possible in all the images, wherever they appear.

Fig. 1. Footprints of balloon images. D. Mavromati, 2006

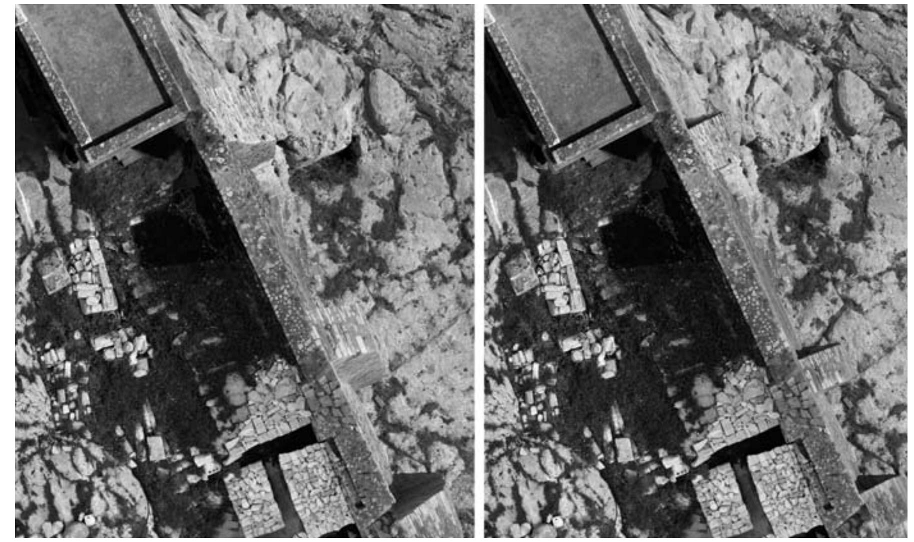

Fig. 3. Part of the east circuit Wall of the Acropolis. Incorrectly depicted features (left). Final orthophotograph (right)

In addition it is desirable that the ground control points are pre-signalised. When this is not possible, however, they must be carefully identified, particularly if significant perspective distortion is present as a consequence of surface relief and image tilt.

Another important matter is that platforms of this sort cannot support heavy cameras. Only light, non-metric cameras of small or medium format can be used. Thus, to the difficulties of bundle adjustment, the unknown geometry of the camera and the strong radial lens distortion (chiefly of the wide-angle lenses) must be added.

Crucial for both geometric accuracy and optical quality of the final orthophotography is also the accurate description (modelling) of the surface of the object. This modelling is done with the breaklines and elevation points. Automatic collection of elevation points with the use of suitable software is in general unsuitable for applications used for the monuments because of the poor texture or great reflectivity of their surface, and because of the many occlusions.

Usually, manual stereoscopic measurement is still the main mode of collection. If a commercial software is used, all the photogrammetrically collected elevation points and breaklines are typically intergraded by 2D Delaunay triangulation into a surface mesh

Fig. 4. Original image of the elevation of the east side retaining wall of the cavea of the theatre of Dionysos. Photo S. Gesaphidis - A. Santrouzanos, 2005

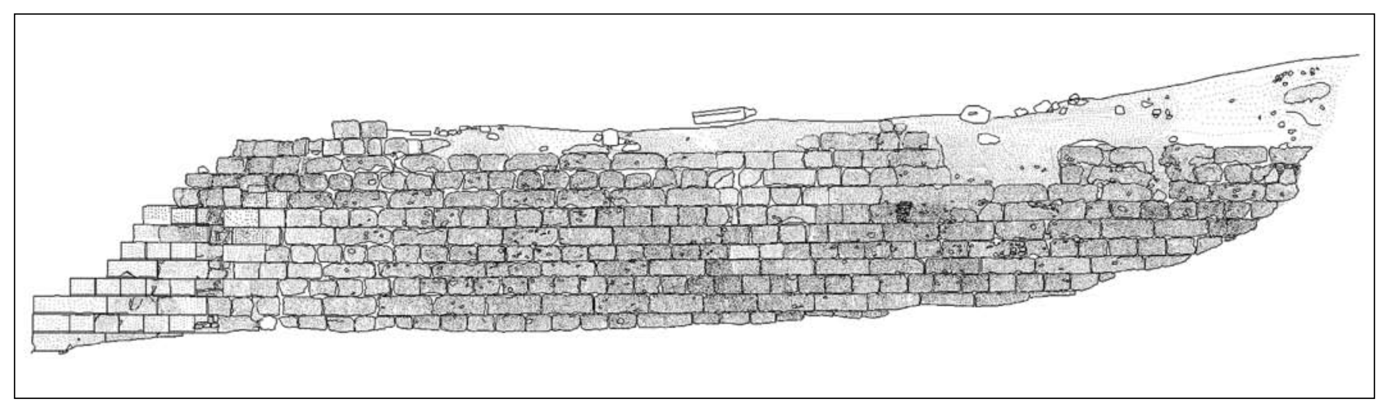

Fig. 5. Plan of the digital surface model of the elevation of the east side retaining wall of the cavea of the theatre of Dionysos. D. Mavromati, 2005.

Fig. 6. Detail of the orthophotomosaic of the elevation of the east side retaining wall of the cavea of the theatre of Dionysos. D. Mavromati, 2005

defined by triangles, with one single value Z for each planimetric XY location.
Thus one of the most usual problems in the collection of the digital surface model of the most ancient monuments, characterised by abrupt changes in relief, is the modeling of surfaces that are parallel to the direction of projection.

Therefore great attention, experience and full control over the stereosopic models is necessary –during the collection phase– for determining the areas that "should" be projected. Needed likewise is full knowledge of the geometry of the object that is being documented. Indeed inaccurate description or locally incorrect description of the surface leads to geometrical errors and to deformations, as can be seen in the examples that follow.
In figure 2 are shown two different orthophotographs of a single area of the tower of the temple of Athena Nike. The orthophotograph at the left has been made from a digital surface model that was created automatically. Even if the deformation of the scaffolding is overlooked, the deformation of the blocks is so great that the specific product is practically useless to the final recipient, the architect and the archaeologist. It is obvious that the orthophotograph at the right is the acceptable photogrammetric deliverable. Correspondingly in figure 3, in the orthophotograph at the left, the side part of the buttresses of the east circuit Wall of the Acropolis is incorrectly depicted, this part should not be projected (orthophotograph at the right).
All the above difficulties and peculiarities that are confronted by the photogrammetrist while elaborating an archaeological survey are demonstrated in the following examples of photogrammetric studies.

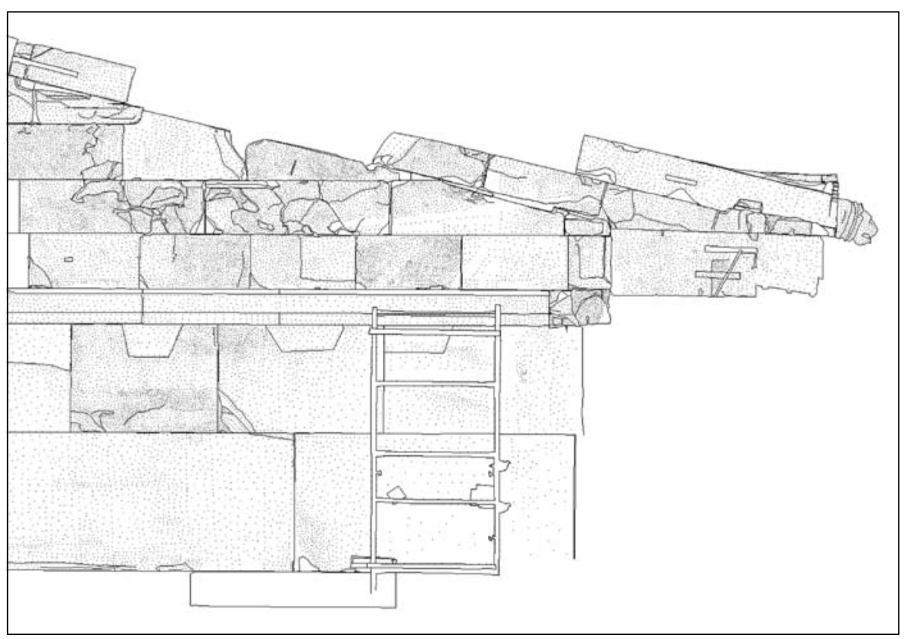

Fig. 7. Plan of the digital surface model of the north corner of the east elevation of the entablature and the pediment of the west side of the Parthenon. D. Mavromati, 2009

A) Elevation of the east side retaining wall of the cavea of the theatre of Dionysos

The study was carried out in 2005 after a request by the Committee of the Sanctuary and Theatre of Dionysos-Asklepieion on the South Slope of the Acropolis to the Directorate of Topographical Photogrammetry and Land Register of the Ministry of Culture and Tourism. The images were taken from a distance of 8m with an analogue camera of medium format (60x45mm) with a 45mm wide-angle lens by S. Gesaphidis and A. Santrouzanos (Directorate of Topographical Photogrammetry and Land Register). A total of 30 images were used with overlapping that surpassed 75%. A total of 244 ground control points (detail points) were measured by E. Portelanou, A. Kambourakis, P. Petropoulos and V. Kyriakopoulos (Directorate of Topographical Photogrammetry and Land Register) and the phototriangulation of 30 images was accomplished with a Route Means Square (RMS) of 7mm in the ground control points. The scale of the final orthophotomosaic was 1:20 (figs. 4-6).

B) East elevation of the entablature and pediment of the west side of the Parthenon

This study is a continuation of the photogrammetric study of the elevation of the entablature and pediment of the west side of the Parthenon that was completed in 2008, the results of which have already been published in the 8th fascicle of "The Acropolis Restoration News". The images were taken in November 2008 with the assistance of the photographer S. Gesaphidis (Directorate of Topographical Photogrammetry and Land Register of the Ministry of Culture and Tourism), using a digital camera 12 MP (full frame, 24x36mm, 4368x2912 pixels) with a 35mm lens. A total of 105 images were used with overlapping that surpassed 75%. A total of 102 ground control points were measured by I. Partsinevelos and the phototriangulation of 105 images was accomplished with a Route Means Square of 2mm in the ground control points. The scale of the final orthophotomosaic is 1:10. The study is continuing and the production of orthophotomosaics of the north, south corner and architrave blocks at a scale of 1:10 has been completed (figs. 7-10).

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Fig. 8. Detail of the original image of the north corner of the east elevation of the entablature and the pediment of the west side of the Parthenon, 2008

Fig. 9. Detail of the orthophotomosaic of the north corner of the east elevation of the enablature and pediment of the west side of the Parthenon. D. Mavromati, 2009

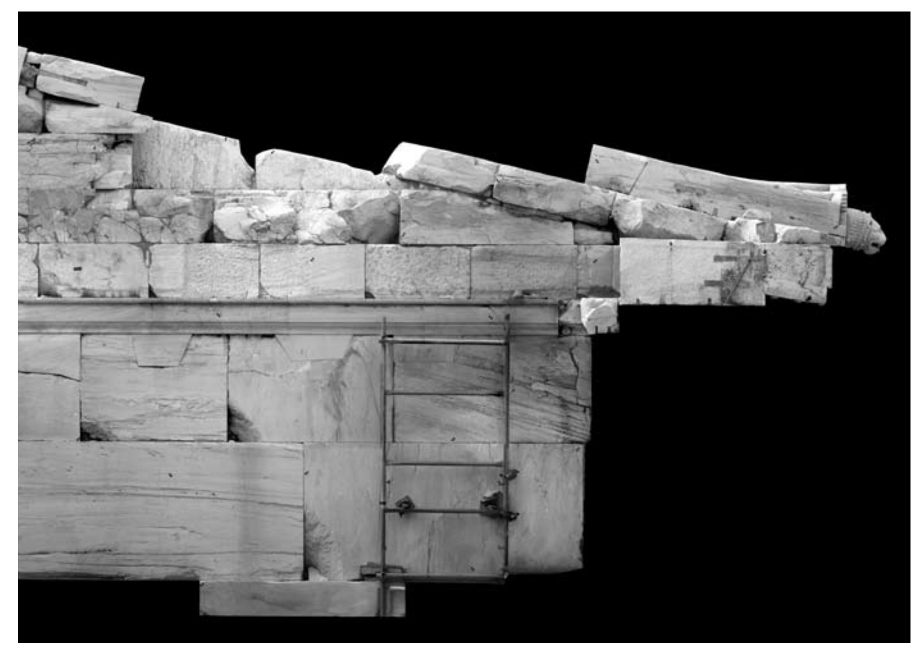

Fig. 10. Orthophotomosaic of the north corner of the east elevation of the entablature and pediment of the west side of the Parthenon, D. Mavromati, 2009

Introduction

The geometric recording of one of the most important archaeological sites worldwide, the Acropolis of Athens, is a challenge for any surveyor and researcher in the field of surface modeling. The challenge lies not only in the importance of the site as an archaeological monument, but also in its size as an object to be plotted, in its variety, in its strong relief and in the existing special conditions.

The photogrammetric survey of the rock and the Walls of the Acropolis formed the greater part of the work "Development of Geographical Information Systems on the Acropolis of Athens". The photogrammetric section of the work was concerned with the production of orthophotomosaics at a scale of 1:100 (pixel size 10mm, precision <3cm) for the plan of the rock, at a scale of 1:50 (pixel size 5mm, precision <1.5cm) for the exterior and interior faces of the north, west and east Wall, and at a scale of 1:25 (pixel size 2mm, precision <1cm) for the areas of the Wall of special interest (areas incorporating members of the monuments).

Fig. 1. The balloon system
Photo V. Tsingas, 2009

Realising the importance of the work, the contracting company surveyed, without extra cost, the entire north, west and east Wall at the scale of 1:25 that had been planned for areas of special interest, including in the survey also the south Wall, which had not been planned as part of the work, so that there would be a survey of the entire Wall, all at the same scale.

Photogrammetric survey has distinct phases of work, the main being shooting the images, orientation of the images, making a digital terrain model and producing orthophotomosaics. The methodology that was applied, the equipment and the software used, the problems faced in each stage of the work are the subject of this report.

Photography and orientation of the images

System of photography

Since the use of any motor vehicle (helicopter or UAV) above the Acropolis monument is prohibited, a balloon system had to be employed for the shots. A helium balloon three meters in diameter was chosen that was capable of lifting the weight of the camera and the accompanying equipment (fig. 1). The 22 MP (5336x4008 pixels) camera that was used, having a medium format of 48x36mm, 9μm pixel size, 12 bit radiometric resolution and a wide angle lens of 45mm. For successful vertical shots the camera was suspended from a gyroscopic system. The shooting system was equipped with a GPS receiver, wireless communication through a long-range Bluetooth appliance and wireless video-camera for a preview of the images. Through the Bluetooth appliance, the shooting system was connected with a portable computer. With the help of suitable software, the computer operator could follow in real time the position of the system through a GPS receiver and could release the lever of the camera at the determined shooting positions.

Making the images

The flights were planned with special care because the strong relief of the ground along with the height variations of the monuments (Parthenon, Erechtheion, Propylaia and the temple of Athena Nike) could lead to occluded areas in the images. Appropriate software was used for designing the shots. For photographing the top view, an average height of 22m from the ground was chosen (scale of image ≈ 1:500) giving a ground pixel measuring 4.5mm, adequate for the resolution of the final orthophotomosaics, while each image covers around 24x18m of the ground. The shots were planned in this way so that the images taken would cover around 75% forward and sidelap and the base on the North-South axis would be about 6m and on the East-West axis about 4.5m. In this way we were able to ensure the multi-image coverage of all areas in the site, a presupposition for producing a full and accurate digital terrain model. It is worth noting that a special flight plan was adopted for areas of strong relief (Parthenon, Erechtheion and Propylaia).

The architectural and historical aspect of the site is not concentrated only on the visible erections of the hill, but also on the surrounding walls, valuable for the quantity of material from various Acropolis structures built into them. For this reason the Walls (north, east and west) were photographed from an average distance of 5 meters (image scale ≈ 1:110) with a pixel size smaller than 1mm on the ground, while the coverage of the image was 5.3x4m. In the case of the Walls, since they did not have strong relief, multi-image coverage was not a demand and thus the conventional image configuration was maintained at 65% for the horizontal orientation, and 35% for the vertical direction.

To obtain the desired accuracy, predetermined control points were used that had been set before taking the photographs. The shots were made by a team of five people, a necessary arrangement for controlling the balloon and the digital camera equipment. Shooting the photographs was the most difficult part of the work because of the special circumstances pertaining on the Acropolis rock. The greatest difficulties had to be handled, such as heat and especially windy weather on the hill, visitors and the existence of worksites for restoration of the monuments.

To take the balloon shots, relative calm is necessary. The Acropolis hill, however, is exposed to winds so that suitable time for the shots was limited to a few days of the year and to 1-2 hours per day. During the shooting the arrival of visitors to the rock never ceased, while only a small part of the area was closed for a short time. Finally the existence of worksites (cranes, scaffolding, workers), as well as the restoration works of the monuments, made shooting of the images especially difficult.

Altogether more than 5,000 images were taken, out of which 1,654 were used for the top view (including 87 additional shots of the Propylaia) and 2,250 for the exterior and interior views of the Walls.

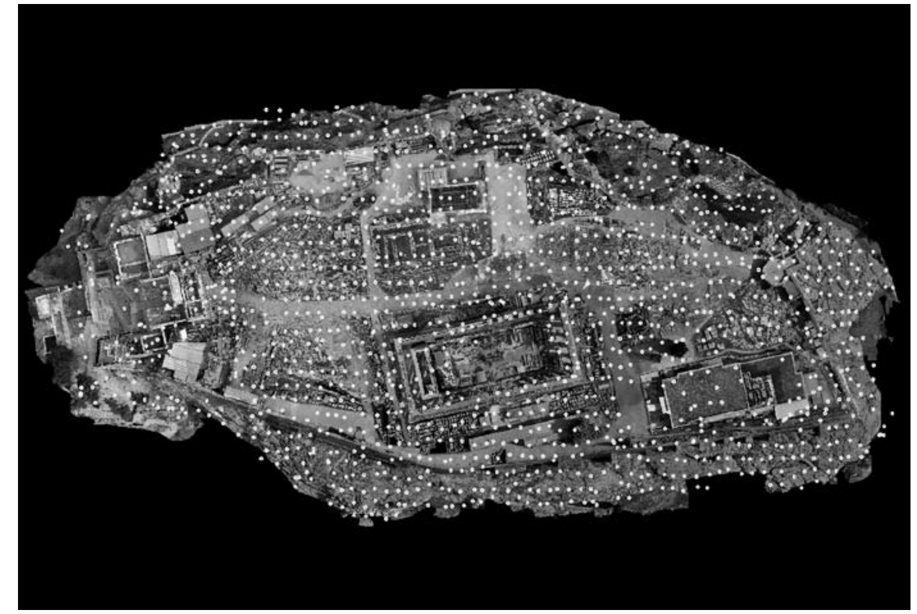

Fig. 2. Diagram (virtual centre) of the shots for the ground-plan

Calibration of the camera

Since the camera employed was not a photogrammetric one, it required calibration and the parameters of interior orientation had to be determined accurately. The interior geometry of the digital camera was recovered through the bundle adjustment method using a network of 30 previously marked points, which were measured with an accuracy of less than 2mm (fig. 2). Four adjustments were performed, three at a distance of 10, 5 and 2 meters, which were connected with the images of the Walls, and a fourth from a distance of 22 meters for the vertical shots of the plan. In all four cases 15 images were oriented, with particular emphasis placed on their turns (kappa=0 and kappa=90) in order to assure the best geometry. The calibration was accomplished using self-calibrating bundle adjustment. For the aerial images (22.5m) simultaneous calibration with phototriangulation (on-job calibration) was applied to a large section of the plan.

The results of the calibration are summarised in table 1, in which c the camera constant, x0, y0 the principal point and k1, k2 the two coefficients of the radial distortion.

Orientation of the images

Orientation of the images on the site is accomplished by means of phototriangulation, that is, calculation of the coordinates of the virtual centers and angles of tilt in a single system of coordinates (HGRS 87). For the phototriangulation, software was used that provided self-calibration. Single-photograph measuring of the tie points was carried out to begin with, and then corrected stereoscopically.

For the top view images, the solution was calculated on a single block (1,654 images), which was oriented using bundle adjustment triangulation relying on well distributed control and check points. An accuracy of 1.7cm average square deviation at the ground control points was achieved.

For the walls image orientation, 34 blocks were created that define the relative planes of sections of the Walls and were solved separately in arbitrary coordinate systems.

	Distance of shot			
	2m	5m	10 m	22.5m
Accuracy				
σo (pixel)	0.204	0.306	0.252	0.2027
RMS X (m)	0.001	0.002	0.002	0.0017
RMS Y (m)	0.002	0.005	0.005	0.0047
RMS Z (m)	0.001	0.002	0.001	0.0021
Interior orientation				
c (mm)	46.1745 ± 0.0065	46.0998 ± 0.0136	45.9117 ± 0.009	45.9503 ± 0.0111
x0 (mm)	0.2007 ± 0.0043	0.0393 ± 0.0063	0.0597 ± 0.007	0.0837 ± 0.0060
y0 (mm)	-0.0721 ± 0.0041	0.0424 ± 0.0063	0.0142 ± 0.008	0.0735 ± 0.0061
κ0	-	-	-	-
k1	$-3.83\cdot10^{-5} \pm 5.05\cdot10^{-7}$	$-4.02\cdot10^{-5} \pm 3.93\cdot10^{-7}$	$-4.01\cdot10^{-5} \pm 5.51\cdot10^{-7}$	$-3.90\cdot10^{-5} \pm 4.32\cdot10^{-7}$
k2	$1.57\cdot10^{-8} \pm 6.59\cdot10^{-10}$	$1.92\cdot10^{-8} \pm 4.95\cdot10^{-10}$	$1.96\cdot10^{-8} \pm 7.12\cdot10^{-10}$	$1.82\cdot10^{-8} \pm 6.93\cdot10^{-10}$

Table 1. Results of the calibration of the camera (45mm lens)

The coordinate systems were rotated according to the planes defined by the control points of each block. The solution of each block had better than 0.6cm average square deviation at the ground control points.

Production of a digital terrain model and orthophotomosaic

Production of a digital terrain model
As has been shown in actual practice, the reconstruction of complex objects by means of algorithms of automatic terrain extraction techniques (with the identification of areas/geometric characteristics) is in most cases unachievable due to occluded areas and great differences in scale between the images. Thus, to a great extent, a manual correction of the digital terrain model is required, which is especially time-consuming. In order to produce a digital terrain model, both the collection of elevation points with the necessary density and the digitisation of the breaklines (lines of discontinuity) are required. In the case of the Acropolis, digitisation of all the characteristic details is required (fig. 3) in order to generate true-orthophotos.
The digital terrain model of the top view was generated with automatic terrain extraction techniques at a resolution of 0.02m and 0.01m, for the top view and the walls respectively. The results were corrected manually using suitable collection techniques such as stereoscopic observation and measurement, thus improving the final quality.

Fig. 4. Digital terrain model in the area of the Erechtheion

Fig. 3. Breaklines (lines of discontinuity)

In figure 4 one can see the especially high resolution digital terrain model of the area of the Erechtheion, which was the result of the combination of elevation points and breaklines.
In the case of the Walls, additional elevation points were used that were acquired by scanning the Walls with a laser scanner after their transformation to each coordinate system and further stereoscopic inspection.

Production of orthophotomosaics
To produce the orthophotomosaics, the rough anaglyph requires the exploitation of specialised "true-orthophoto" methods, which the most conventional orthorectification programmes lack.
To produce true orthophotomosaics it is necessary to apply special algorithms. In cases where the terrain has strong height variations, the conventional orthorectification programmes can yield unexpected results, such as double projections and displacement artifacts. In order to resolve these issues it is necessary to monitor the visibility in the direction of the images and, at the same time, to detect the occluded surfaces on the original images. On this basis, the production of orthophotos (figs. 5-7) was achieved through a specialised orthorectification programme.

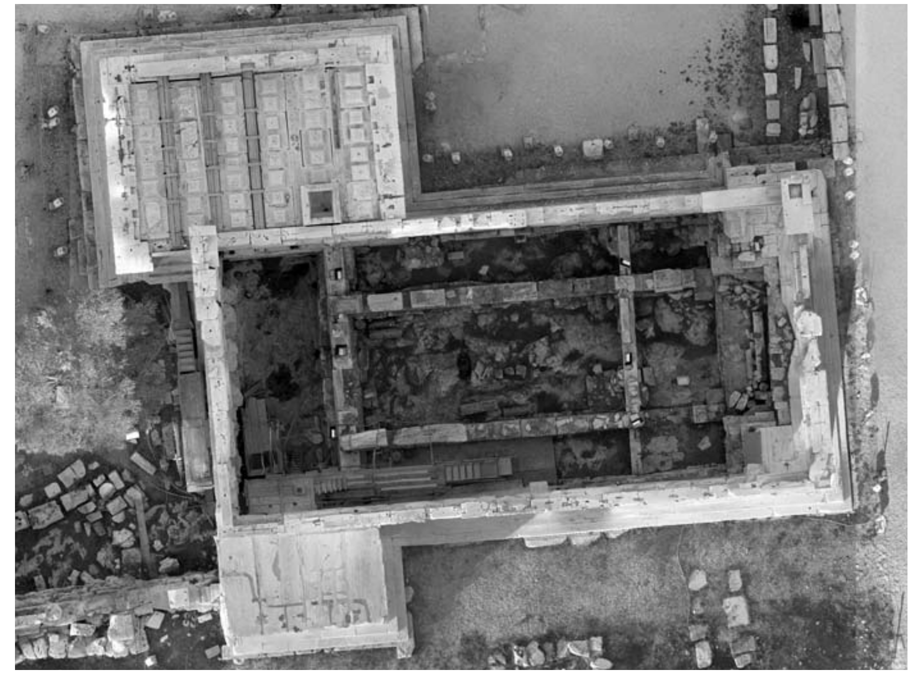

Fig. 5. Orthophotomosaic of the top view (Erechtheion).
Study for the development of GIS on the Acropolis of Athens, 2009

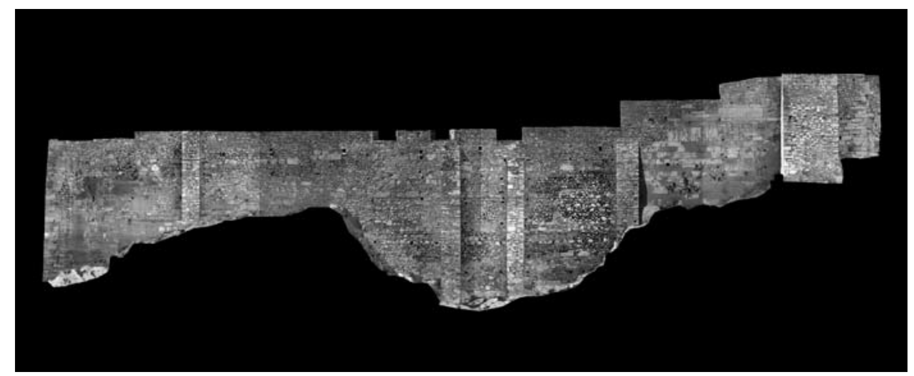

Fig. 6. Orthophotomosaic of the outerview of the east Wall.
Study for the development of GIS on the Acropolis of Athens, 2009

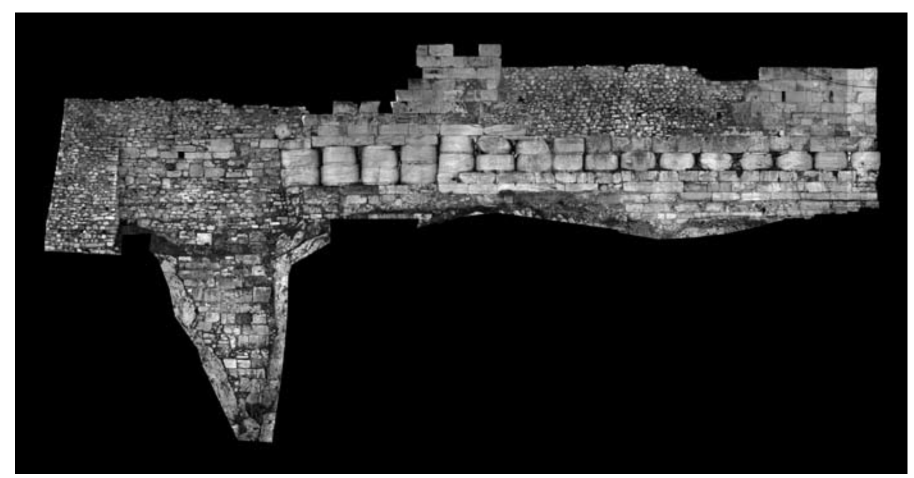

Fig. 7. Orthophotomosaic of the outer view of part of the north Wall.
Study for the development of GIS on the Acropolis of Athens, 2009

Summary
The most advanced methods and computer software were used for the photogrammetrical survey of the Acropolis Walls. Especially, in the case of cultural documentation, where the accuracy requirements increase dramatically and the visual quality of the final products is indispensable, the fusion of different state-of-the-art methodologies is a demand.
Although aerial photogrammetry has recently made a noticeable progress in the direction of automation (automated orientation and DSM extraction), in close-range applications such as this one, human interaction is still very important. Especially during the stage of DSM production, only the stereoscopic check and correction can ensure a "true" three-dimensional model. This holds also for the orthophoto generation, even when specialised true-orthophoto generation software has been employed.
The current project, due to its complexity and archaeological interest can be characterised as an important case study for similar research, involving large and complex cultural heritage sites.
The orthophotomosaics of the top view and the Walls can be seen in full resolution on the project's website **http://acropolis-gis.ysma.gr.**

Dr Vasillios Tsingas
Rural and Surveying Engineer
ELPHO

Works in the field

Equipment
• Dual frequency geodetic GPS receivers.
• Servogeodetic total station with an angular precision of 3´´.
• Digital level with leveling precision of 0.3mm per km.
• Three-dimensional laser scanner.
• Digital hand-held camera 10 Mpixel.
• Balloon with digital camera 22 Mpixel.

Geodetic Infrastructure
The following procedure was used in order to assure a common coordinate system compatible for all measurements made with the 3D scanner:
1. A unified triangulation network was established using the GPS system.
2. Fully dependent traverses were attached to this network.
3. Precise leveling carried out determining precise elevations directly to most of the triangulation and traverse points.
In this way a unified geodetic infrastructure was established for the entire extent where the scanning is to be done, with precision of one cm.

Organisation of points from which scans are to be made
The principles on which the procedure for choosing scanning points was based were the following:
1. Assuring the greatest possible coverage of the object of the scanning with the lowest number of scans.
2. Admissible angles of shooting the object.
3. Assured coverage between successive scans in all directions.
4. Recording and mapping of the scanned surfaces in order to assure, in case of an evaluation error, that as few as possible of the surfaces have been missed in the scanning.
5. Assuring that the scans, to the extent possible, are made from points on the basic polygonometric network and blind traverses are avoided.

Figs. 1-2. Vertical scanning from the top of the Wall. Photos C. Liapakis

Principles in the procedure of scanning - Registration of the scans
The procedure of scanning must assure the accuracy of the measurements, as well as the possibility of their being integrated into the established geodetic infrastructure with the greatest possible accuracy. To achieve this, in each scan made with the scanner leveled, the procedure followed was:
1. The scanner was placed on a known position chosen in advance, and oriented toward another point with known coordinates.
2. Targets were used with coordinates that had been determined geodetically for further orientation of the scan.
3. Spheres were used for orienting successive scans.
4. The successive scans were oriented entirely using the two above methods, while the relative orientation between the scans was assured through the use of common targets and spheres.
5. In addition, it was made certain that the successive scans covered surfaces overlapping in such a way that the scanning of common objects would assure the additional possibility of relative orientation.
In cases where the scanning was carried out with the scanner unleveled, all the other methods of orientation of the scans mentioned above were used, except of course the first.

Clearly the methods of orientation that were used were in every case far more than what was necessary. The logic was that since the process of scanning is especially difficult, it would be preferable to avoid any likelihood of having to repeat the measurements. Each method, moreover, depending on the circumstances, may prove to be more useful than another. Finally, it should be noted that the methods of relative orientation have been shown in practice to be extremely accurate, but with the disadvantage that they transfer the error of absolute identification, whereas, vice versa, absolute orientation is less accurate, but it assures absolute precision of the entire model.

Exterior photography (shots from the ground, balloon shots)
The analysis of the digital image produced by the camera incorporated in the digital scanner for the measurements was not enough to meet the standards required. Therefore an exterior digital camera with analysis of 10Mpixels, was used.
Digital image recording of the object followed these basic principles:
1. Image shot conforming with the basic rules of photography (correct shutter speed and diaphragm setting, balanced lighting, compliance with greatest acceptable distance, correct focusing, etc).
2. Image shots of the object, to the extent possible, directed at a right angle (the use of the interior camera of the scanner usually makes this impossible for shooting photographs).
3. Images of compound surfaces from more than one side.
4. Balloon images in order to render the texture of horizontal surfaces.

Supplementary scans - Vertical scans
As was expected, despite taking all the appropriate measures to record precisely the surface of the object being scanned, gaps were found in the scan that were due to human error. Significant gaps, were also found in the scan, however, which were due to the fact that the relief itself was masking certain areas of the object. The gaps that were due to human error were covered by supplementary scanning. Two methods were used for coping with the gaps that resulted from the impossibility of scanning because of the relief:
• With vertical scanning, since with a custom apparatus mounting method it was possible to scan walls and inaccessible areas from the crown of the circuit Wall (figs. 1-2).
• By making a digital model of the ground from a photogrammetric rendition.

Office work

Solving triangulation networks - traverses - leveling networks
The triangulation network was resolved commonly with the traverse network, and with geometric leveling. The precision achieved was equal to or better than that required. The methodology was a three-dimensional least square adjustment technique, that assured the compatibility of all the observations in a common environment (fig. 3).

Registration of the scans - techniques employed
A suitable software package was used for processing the scans. For absolute and relative registration of the successive scans all the techniques available in the software package were utilised, as described in the following:
1. The scans made with the scanner leveled were registered, to begin with, using the coordinates of the point where the scanner had been set and the coordinates of the point used for the initial orientation of the scan, as is the case with a geodetic total station. Furthermore, these scans were oriented using points with known coordinates or spheres that had been scanned previously and had already been oriented. The resolution is accomplished as a unit by the software package with the Least Square Adjustment technique.
2. The scans made with the scanner unleveled were registered either using targets with known coordinates or spheres, the position of which had been determined in a previous scanning, or finally with a relative orientation using points common to another, already oriented, scan. In general, in each case more than one of the above methods were employed.
The software package assured common resolution with the methods outlined above in more than one scan simultaneously. An effort was made to achieve a common resolution of the entire model that would assure the greatest possible accuracy in the orientation of the scans. Due, however, to the limits enforced by the size of the archive, common registrations were made on as many scans as possible but not on all. Overlapping assured compatibility between the registrations of groups of scans.

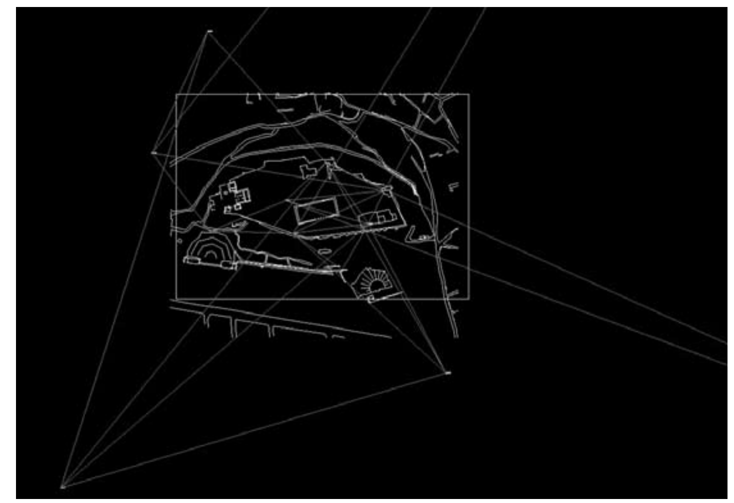

Fig. 3. Triangulation network

Determination of gaps in scans
With common registrations of the scans it was possible to unify them and, subsequently, it became possible to locate gaps between successive scans, and also within the same scan. The gaps, depending on what caused them, were handled with the same procedures as those described in *Works in the Field*.

Entry of supplementary scans - entry of digital model of the ground from a photogrammetric rendition
The supplementary scans, depending on how they were taken, were registered absolutely and relatively using the methods outlined above. In particular, the vertical scans taken from the crown of the Wall downwards, were mainly registered relatively using common points with the existing scans, since it proved to be very difficult for objects

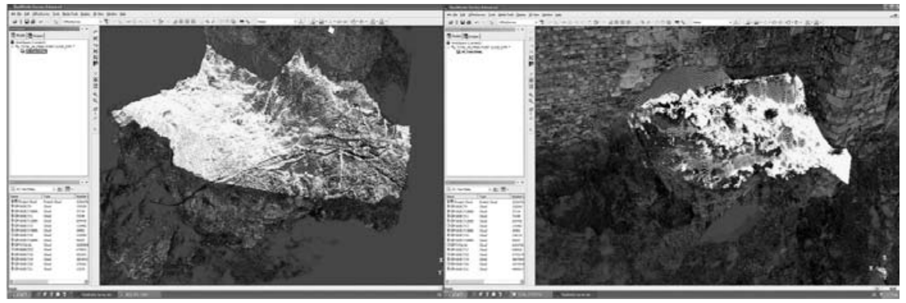

Fig. 4. Compatability of the three-dimensional scanning with the digial terrain model

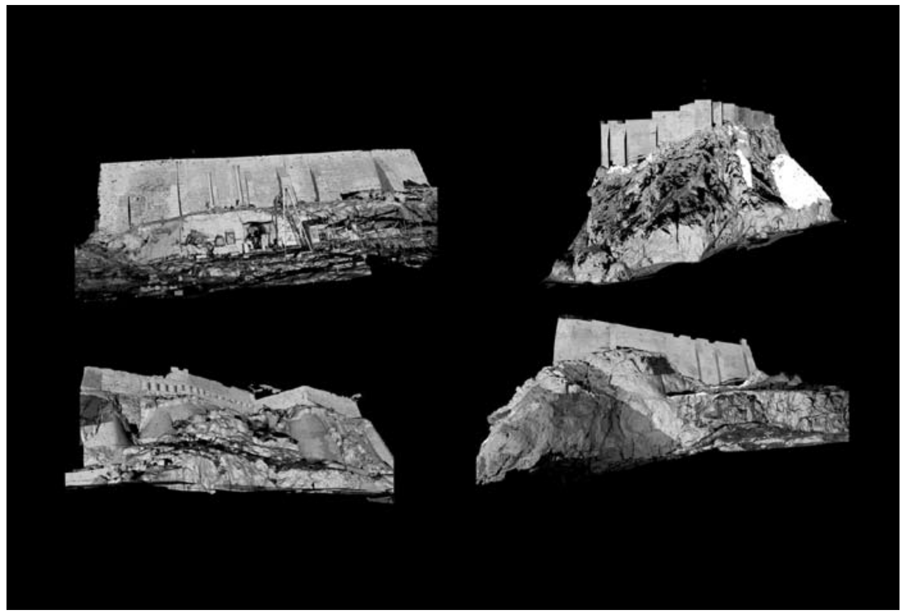

Fig. 5. Creation of a single model of point clouds

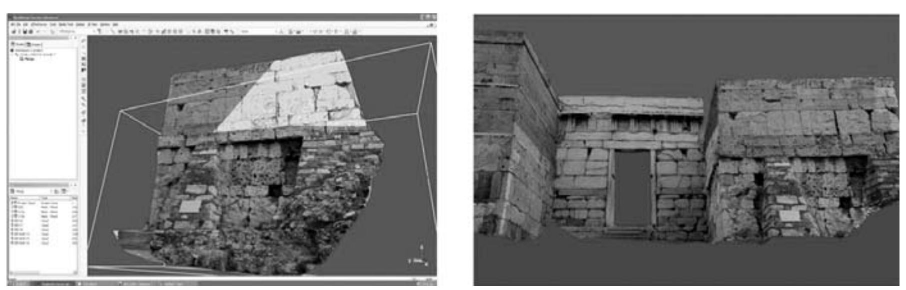

Fig. 6. Precision of orientation of the images

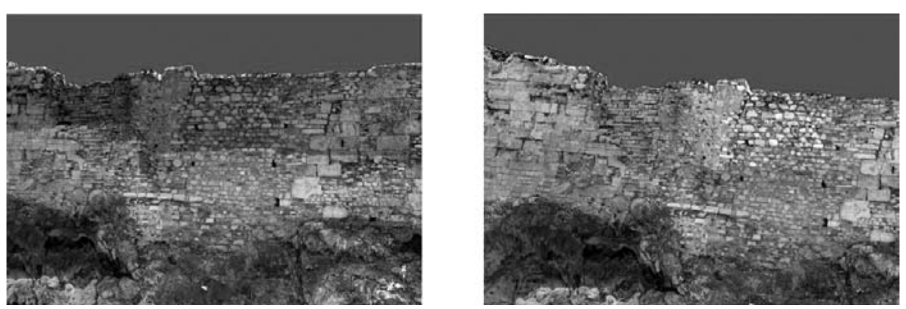

Fig. 7. Balancing the colour tones of the digital images

and spheres to be set and measured, given the especially difficult relief and the orientation of the scans. Even so, the method used proved to be particularly accurate, since the bulk of the scans had been absolutely registered with great precision and the vertical scans, which depended relatively on these, were registered with corresponding accuracy in respect to the absolute registration. The relative registration was indeed particularly accurate and it assured the compatibility of the two models.

Wherever the gaps of the object could not be covered by the previous scans and the gap areas were visible from a vertical direction, a digital terrain model was employed that was created from a photogrammetric rendition of the models based on balloon photographs. Yet again, the compatibility of three-dimensional scans with the digital terrain model demonstrated the unified accuracy that was assured by the use of the common geodetic background (fig. 4).

Filtering of scanned data

Before establishing the surfaces, the point clouds of the successive scans were checked and the points that had been covered were appropriately filtered.

Creation of a single model of point clouds

By unifying the scans a single model of point cloud was created. In order to process the database, because of its enormous mass of data, it was divided into smaller models (fig. 5).

Orientation of digital images

For the orientation of the exterior digital images to be possible, achieving the greatest possible accuracy, the full point cloud had to be used in combination with the relevant point intensity. Thus the point cloud that describes the object scanned appears as a three-dimensional photograph on the screen of the computer and enables the operator to recognise easily and accurately common points in the digital images and then to orient the images with the greatest possible accuracy (fig. 6).

Balancing the color tones of the digital images

To balance the color tones of the digital images, a suitable tool available in the software package was employed. Color balancing reduces the differences in tone caused by different conditions while taking the digital images. As a result, a single texture on the object is assured, and variations of chromatic tones are not distinguished (fig. 7).

Generalisation of a model of point clouds

For a model of surfaces to be created, generalisation of the points model was necessary. After a procedure of successive steps to retain a properly detailed description of the object when creating the surfaces model with the greatest possible accuracy and, simultaneously, to allow the processing of the surfaces, within the limits imposed by the software because of the amount of data, we chose a density of discrete points on the Wall and on the rock, that would satisfy these demands. The density of the points on the Wall that were used for creating surfaces was one point per 10cm. On the rock instead, one point per 20cm was used. With this density it was possible to establish three-dimensional surfaces in accordance with what was needed and to apply the images to them so as to give these surfaces texture, as described in the following (fig. 8).

Creation of surface models - Segmentation of model of point clouds so as to create surfaces

To create surfaces, the software that was used offers a series of tools that provide, in each case, a better simulation of the object. The complexity of this specific object meant an especially careful and detailed process of articulating the surfaces. This was connected not only with the geometry or complex relief of the object, but also with the positions from which those images were taken for the purpose of showing the texture of the surfaces. For this purpose the surfaces that were articulated were created from point clouds that had been appropriately segmented. The segmentation was done either to render the

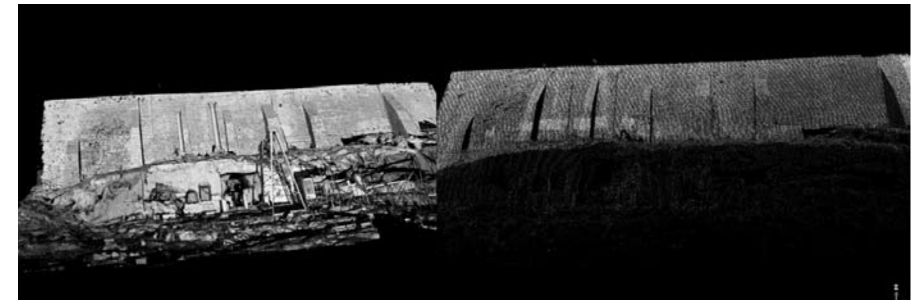

Fig. 8. Generalisation of a model of point clouds

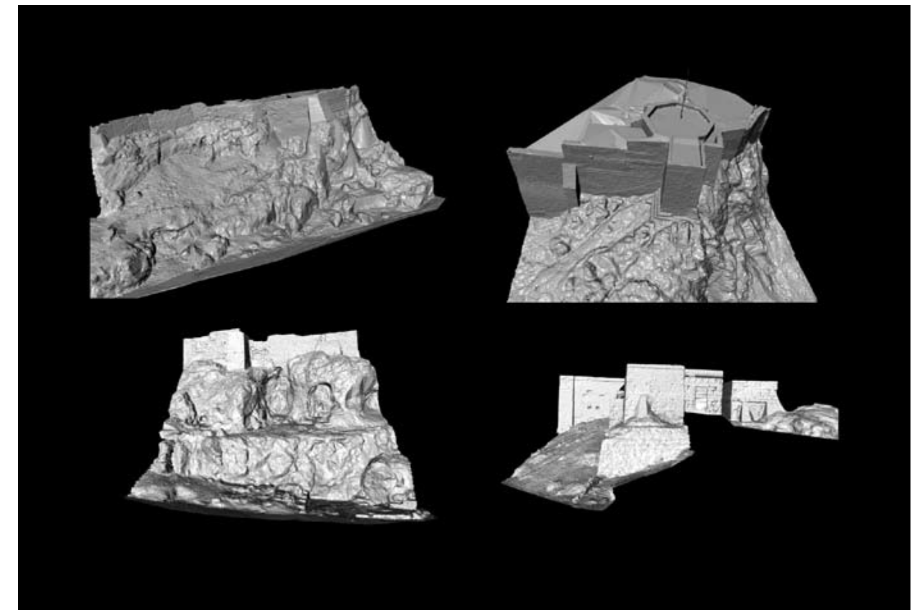

Fig. 9. Creation of surface models

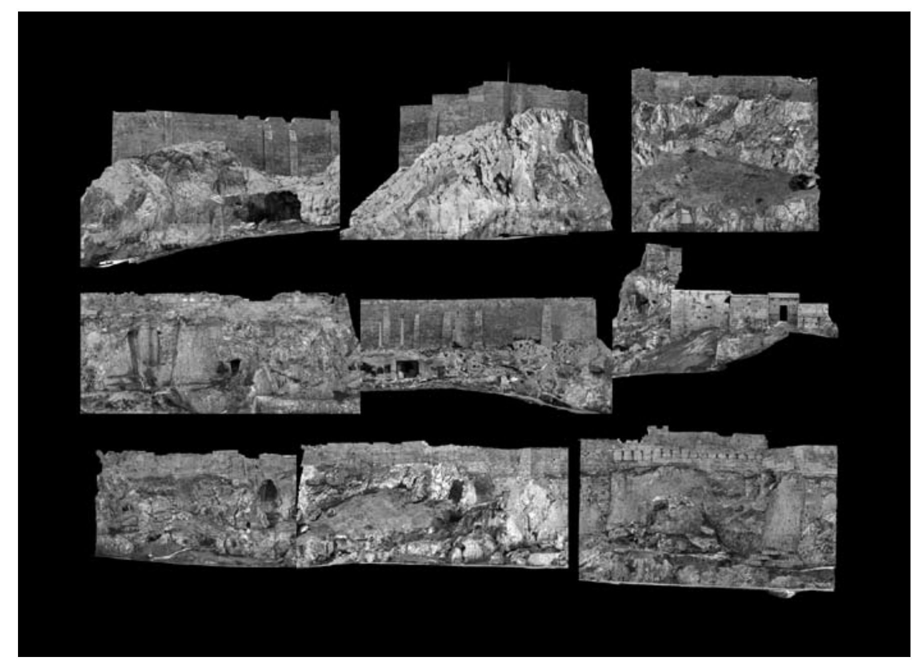

Fig. 10. Creation of final models with texture

geometric data of the surfaces correctly or so that the texture could be added to them, without affecting the rendering of texture in another area of the object. The above process proved to be particularly demanding, stressful and time-consuming. The demand, moreover, for the final model of the surfaces to show a single surface, meant that additional surfaces had to be superimposed within the dividing lines between successive surfaces or else new surfaces had to be covered. This fact required yet another complex procedure (fig. 9).

The overlapping of images so as to render texture

The overlapping of already oriented images on the model of the surfaces was a process that evolved simultaneously with the creation of these surfaces. In this way it was possible to monitor the surface to which texture was being given, so that it could be accomplished using the image most suitable for the case. At the same time we could avoid using this image on a surface covered better by some other image. It is a particularly complex process, that was repeated several times to render the surface with the best possible texture.

Creation of final models with texture

All the preceding procedures that were completed with the creation of surfaces to cover the gaps –where possible because of the nature of the object– resulted in the creation of a single surface model for the Wall and the rock of the Acropolis of Athens, that renders the object faithfully and accurately. The texture rendered on these surfaces led to the creation, moreover, of a photorealistic three-dimensional model of the Athenian Acropolis, that renders with fidelity, accuracy and clarity its appearance in the total area that has never been shown until now (figs. 10-12).

Technical standards

• Density of point clouds for the Wall: 1-2cm.
• Density of point clouds for the rock: 5cm.
• Triangulation network accuracy <5mm.
• Leveling network accuracy <3mm.
• Contracting authority: YSMA

Statistics of the scans and geodetic network

For full coverage of the Wall and rock, interior and exterior :
•125 scans were taken.
• Over 1,800 digital images were taken and used.
• A three-dimensional model of point cloud was made consisting of 330,000,000 points.
• The density of the points was within the requirements.
• Accuracy better than 1cm.

For the geodetic network:
• Triangulation network accuracy <3mm.
• Traverse network accuracy <5mm.
• Geometric leveling accuracy <2mm.

Fig. 11. View of the photorealistic three-dimensional model

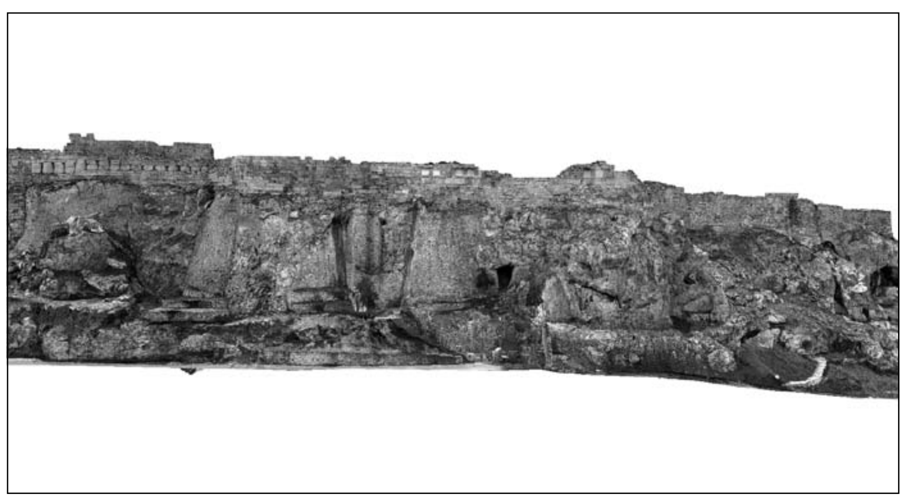

Fig. 12. View of the photorealistic three-dimensional model

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The introduction of digital technology in Photogrammetry and the development of the new photogrammetric techniques or the expansion of those already existing, have contributed greatly to the promotion of Photogrammetry as a fundamental factor in the geometric documentation of monuments of cultural heritage. In particular, the contemporary technology of laser scanning, with the rapid development seen today, allows the fast recording of a vast number of points and the full three-dimensional modeling of complex surfaces, making it an integral measuring tool for photogrammetric survey.

One of the basic purposes of the work "Development of Geographical Information Systems on the Acropolis of Athens" was the geometric documentation of the Erechtheion (fig. 1) combining photogrammetric and laser-scanning techniques, for the purpose of producing a full three-dimensional model of the monument with real photographic texture.

The technical requirements that were determined by the Acropolis Restoration Service (YSMA) itself, defined the resolution of the three-dimensional scanning at 5mm for both exterior and interior areas of the monument (fig. 2), and higher (distance between points less than 1mm) in areas with sculptured decoration and greater archaeological interest, such as the Caryatids. Correspondingly, the final scanning accuracy of the areas with special interest was defined at 2mm or better. Furthermore, for the texture mapping of the aforementioned three-dimensional model, colored digital photographs were made with ground sample distance (pixel size projected on the ground) 2mm at most, ensuring the visual completeness of the reconstructed digital model.

The basic measuring equipment included two different types of laser scanners. The first one was a medium range scanner (fig. 3) based on the phase-shift technology, and capable of measuring objects up to a 15m distance. The measuring accuracy is fairly high (better than 0.5mm), the nominal speed exceeds 200,000 points per second, while the scanning resolution can be better than 1mm. On account of these characteristics, the particular scanner was employed for acquiring the main part of the Erechtheion at the two requested resolutions (5mm and 1mm). Both limited scanning distance and intense surface relief of the monument, resulted in the existence of occluded areas on the model (areas that should be scanned but were not visible from the scanning positions). For that reason, measurements were taken of some specific sections of the Erechtheion using a long range scanner based on the time-of-light technology that allows object scanning up to a 300m distance (fig. 4). Apart from the long range scanning, the measuring speed of the scanner was 50,000 points per second with 5mm accuracy. For the acquisition of some remaining occluded parts, such as the Erechtheion ceiling and some indentations in the upper part of the monument, a photogrammetric mapping method was applied using vertical overlaid images taken by means of a helium balloon. Additionally, signalised control points were measured all over the monument using a highly accurate geodetic station. The individual scans produced by the two scanners were registered in a unified point cloud using the control points and surface matching algorithms. Some of the control points were used for the orientation of the aerial photos of the Erechtheion, providing a direct alignment (due to the common reference system) of the laser model with the surface model that was generated photogrammetrically. It is worth mentioning that the registration of the scans was performed in the field, simultaneously with the measure-

Fig. 1. Side view of the Erechtheion from balloon

Fig. 2. Top view of Erechtheion. Details from orthophotography of the Acropolis rock. Scale 1:100. Study for the development of GIS on the Acropolis of Athens

Fig. 3. Scanning with phase-shift scanner. Photo L. Grammatikopoulos, 2009

ments, in order to detect the occluded areas in situ and to cover them with more scans. Two color digital cameras of normal and medium format were employed for the image acquisition of the monument (ground and aerial views), with resolution of 12MP and 22MP respectively. These images would be used at a later time for the texture mapping of the three-dimensional model. The field work lasted 5 days, including the scanning of the monument by the two scanners, the establishment and measurement of the network of control points and, finally, the image capturing. A total of 1,207 scans and around 400 photographs (ground and vertical) were taken.

The size and complexity of the monument, along with the high accuracy requirements of the specifications, meant that data acquisition and processing were a difficult venture, but also a great challenge with scientific and research interest. The suitable choice of the positions for the measuring instruments, ensuring the greatest possible coverage with the same density of points, the experimental study of the reflection rate of the laser beam onto the marble surface, the careful design and use of the control point network, along with the radiometric uniformity of the shots, ground and aerial, which is definitive for the visual quality of the final photo-textured model, all are characteristic examples of problems that may occur and need special attention during collection of the data. Procedures concerning point clouds processing, such as noise reduction, unnecessary point elimination without affecting the morphology of the object, registration of individual clouds in reference to a single one (fig. 5), alignment of point clouds from different sources, generation of a three-dimensional triangulated surface model (fig. 6) and filling of small holes of this surface based on the local slopes of the relief, prove to be more difficult and time-consuming when applied to such a vast amount of data. It is worth mentioning that the number of initially scanned points was over 5 billion, providing the final triangulated surface model made up of 350 million triangles.

Fig. 4. Scanning with time-of-flight scanner. Photo L. Grammatikopoulos, 2009

Texture mapping of the three-dimensional model using initial imagery was the final stage of the geometrical documentation of the Erechtheion. Figure 7 shows four different views of the full three-dimensional model of the Erechtheion with real photo-texture. Both relief and texture of the surrounding area have been acquired photogrammetrically from the vertical balloon images. The geometric accuracy and visual quality of this mapping method can be easily grasped from figure 8, showing a detailed view of the three-dimensional model of one of the Caryatids rendered with photographic texture. For the texturing process of this model, shots of the original Caryatid in the Acropolis Museum were combined with the laser scan of Erechtheion. On the YSMA

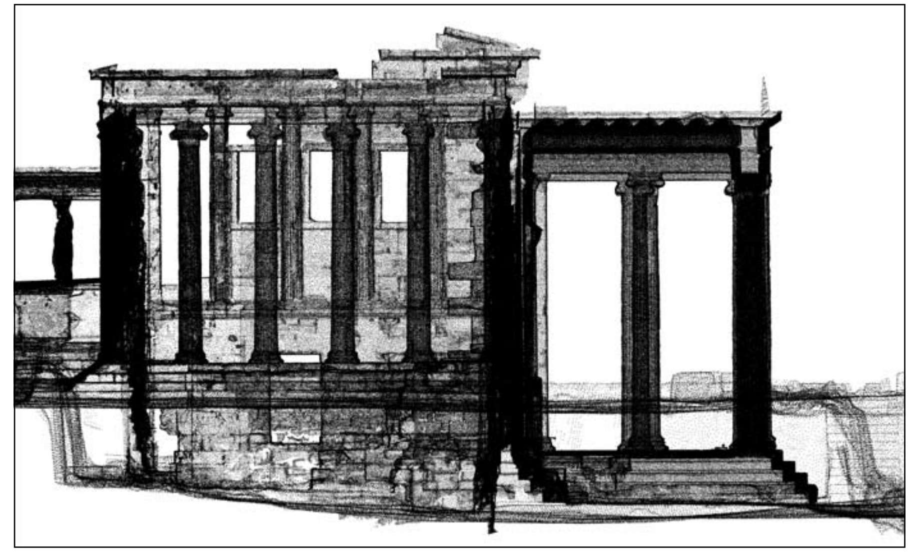

Fig. 5. Part of the unified point cloud

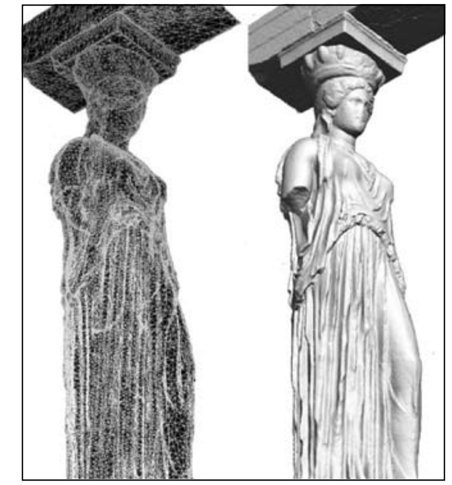

Fig. 6. Details of the triangulated three-dimensional model (without photo-texture)

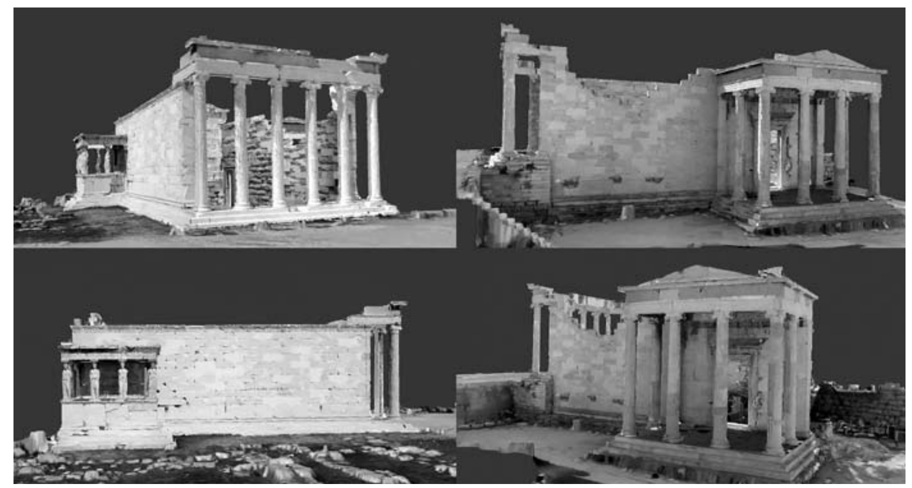

Fig. 7. Views of the Erechtheion (three-dimensional model with photo-texture). Study for the development of GIS on the Acropolis of Athens, 2009

website (**http://acropolis-gis.ysma.gr**) the visitor can explore interactively a simplified version of the three-dimensional model of the monument, along with three video archives presenting two virtual tours of the full model of the Erechtheion, as well as a tour around the digitally reconstructed Caryatid in the new Acropolis Museum.

The final products, consisting of the full three-dimensional model of the Erechtheion with photographic texture and the three video archives, are the result of several different techniques and procedures, but also of the collaboration of researchers from different disciplines, such as Photogrammetry, Topography, Archaeology, Computer Vision, Architecture, Image and Signal Processing, Three-dimensional Processing of Points and Models, Computer Graphics and Video Processing. The presented approach demonstrates that such collaborative efforts contribute not only to the utilisation of new technologies for surveying, but also to the implementation of new techniques and procedures for geometric documentation, conservation and promotion of the monuments of cultural heritage.

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Fig.8. Details of the 3D model of the Caryatid with photo-texture. Study for the development of GIS on the Acropolis of Athens, 2009

The application of computer technology to the Archive of the ESMA restoration works began in 1989. The successive systems employed from time to time, their features and their scope have been presented in the past in various gatherings and publications (see *Acropolis Restoration News* no. 2). We shall therefore limit this presentation to the main improvements and additions that have recently been made in the framework of the 3rd Community Support Framework and the Operational Programme "Information Society".

Before proceeding, two significant features should be borne in mind. The basic form of the system comprises, on one hand the main archive of architectural members of the monuments and on the other hand the archive of photographs, drawings and texts, which documents the information coming from the first (fig. 1). Moreover, the archive of architectural members is organised on the basis of a hierarchical logic of construction, in which the monuments are analysed in sections of the whole and then by architectural member.

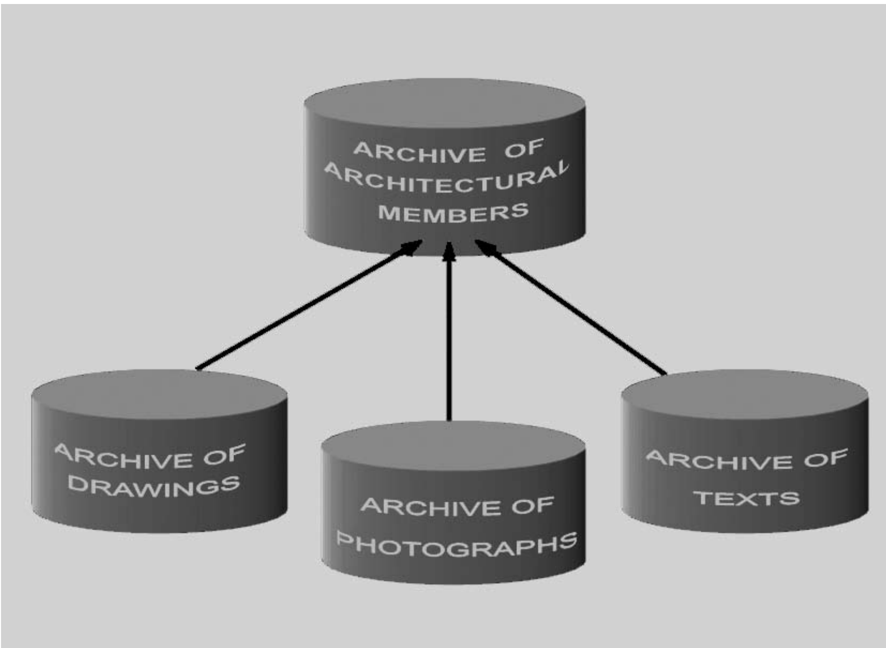

Fig. 1. The main archives in the database and their linkage

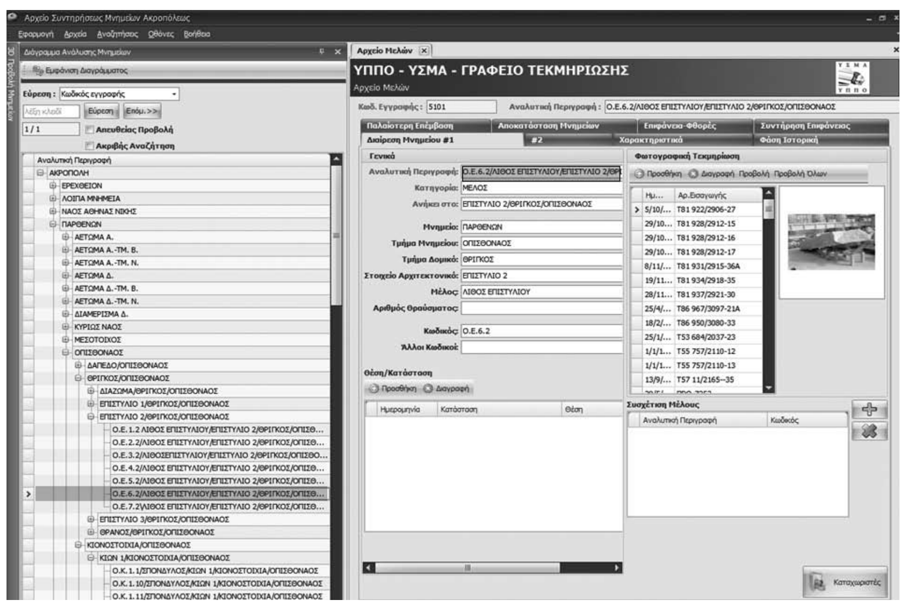

Fig. 2. Shown at the left of the screen is the hierarchical analysis of the monument and the selected architectural member. At the right is the corresponding entry

This hierarchical system is imaged in the database and it provides a very good navigating tool for the contents of the archive of architectural members. In its recent version it is much more functional, since apart from the incorporation of a full "Find" mechanism, it also provides the significant option of presenting the corresponding entry of the archive of architectural members every time that a subdivision of the monument is selected (fig. 2).

A second improvement has to do with the subsystem for processing images. In the display of all the images (thumbnails) of the photographic or graphic documentation, the images can be viewed simultaneously, enlarged as desired. With the use of an image processor details that are frequently difficult to detect in the digitally scanned image of the evidence, are in this case visible. By using simple filters for contrast and brightness of the image, much more information appears than from the frequently misty survey drawings in pencil. Furthermore, an ergonomic digital zoom lens enables one to examine obscure details of the image (fig. 3).

The next point has to do with information about the ancient members that is provided by the mapping of damage and of interventions for the conservation of the surface of the marble. Over the years when the works were in process, eight successive improvements to the original chromatic annotations of the mapping have been used. The archaeologist Stelios Lekakis, who worked for a time on the Propylaia, arranged them in chronological order. These annotations were then incorporated in the new database in such a way that according to the date when a certain plan was composed, the chromatic annotations of the corresponding period can be viewed (fig. 4). Incorporated in the most recent edition of the database, likewise, is a sub-system for extracting statistical data. For example the database can present the histogram of the multitude of documents per archive and per register. Parenthetically, it has to be noted that to date 88,200 documents have been registered.

A most important addition to the software provides the possibility of accessing the architectural members' archives through a three-dimensional graphics environment. The use of a three-dimensional model through which the monument is accessible, is applicable at present only to the Erechtheion, which has acquired a final form, after the completion of the restoration works. We are able to revolve the model so as to choose a desired view (fig. 5).The plan of the view chosen is then displayed –on a GIS background– with the codes of the architectural members as well (fig. 6).The choice in the next stage of a member of the monument shows also the pertinent entry (fig. 7). This process provides a more user-friendly environment, since the user is not obliged to know the interior organisation of the data (this feature applies particularly to access through the Internet).

Accessible in a similar way is a new section of the database concerned with the circuit Walls of the Acropolis. The digital model that has been produced from three-dimensional laser scanning rotates and we can choose a specific area. The chosen section of the Wall links with the Geographical Information System (GIS) where it is divided into square frames of reference and is mapped on different levels of information. The type of data mapped on each level, are appropriately distinguished in different colours. In addition, the objects of special interest that are incorporated in the Walls are described in a subtotal of the database with separate data descriptions.

It should be noted that all the changes in the system, the most important of which we have described above, are the result of the experience gained while using the preceding software. The features of the new system were determined on the basis of observations by Fani Mallouchou-Tufano, who until September 2009 was also the head of the documentation office, the archaeologists of the office, Evi Lembidaki, Elena Karakitsou and Evi Petropoulou, the administrative employee Katerina Liakopoulou and the present author, who were to now the users of the database. In monitoring the new system, noting the problems and determining further desirable improvements, in addition to those mentioned above, the contribution of the Conservation Section was significant. Certain it is that with the increasing numbers of users we will have more observations and comments that will lead to further improvement of the software. Here we would thank the Foundation for Research and Technology of the University

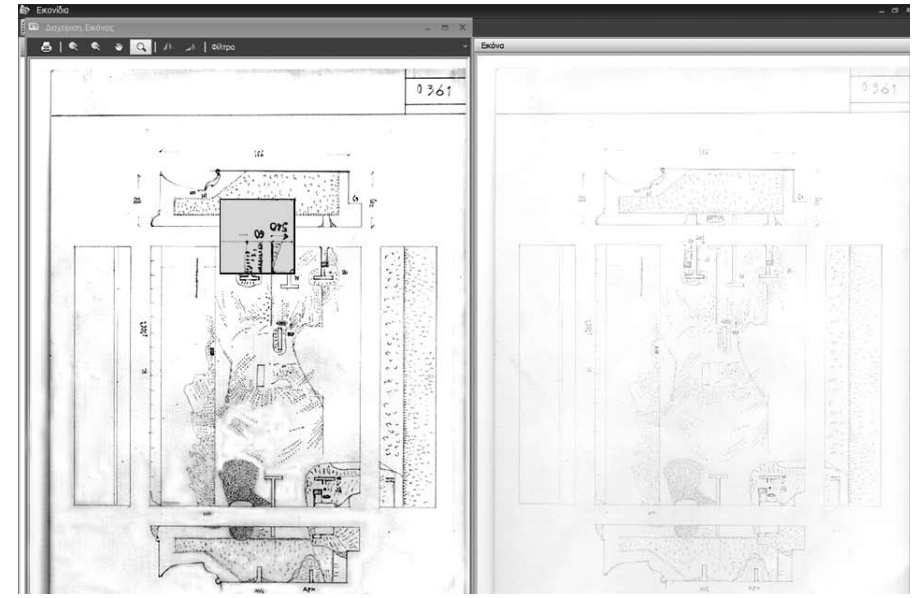

Fig. 3. Shown at the right of the screen is the original image of the digitised drawing. At the left of the screen, the details resulting from the use of the processing tools and the "zoom lens"

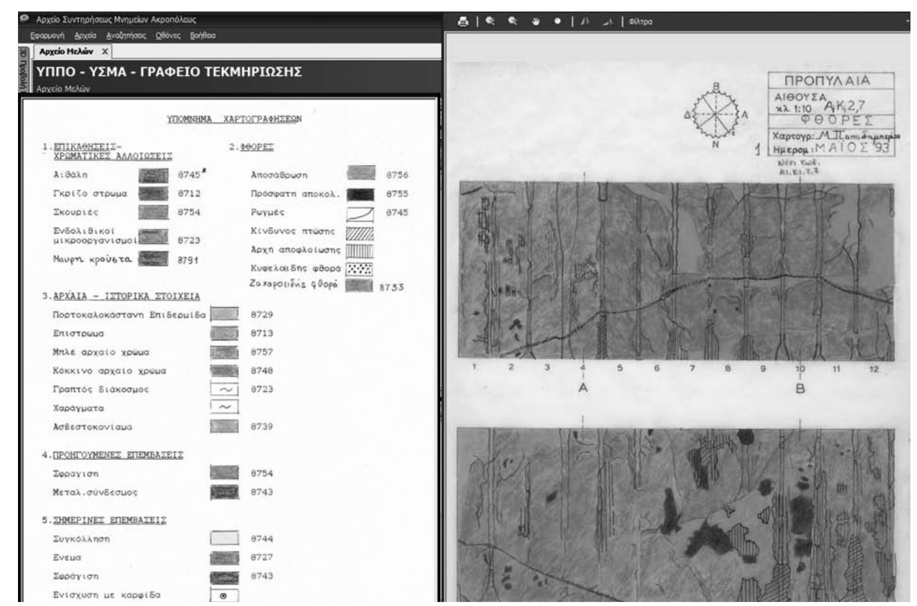

Fig. 4. Shown in colour at the left of the screen is the indication of the damage and interventions to the surfaces of the marble. Indicated in colour at the right is the damage to drum A.K. 2.7 of the Propylaia


Fig. 5. The selection of the south wall in the three-dimensional model of the Erechtheion (1st step)

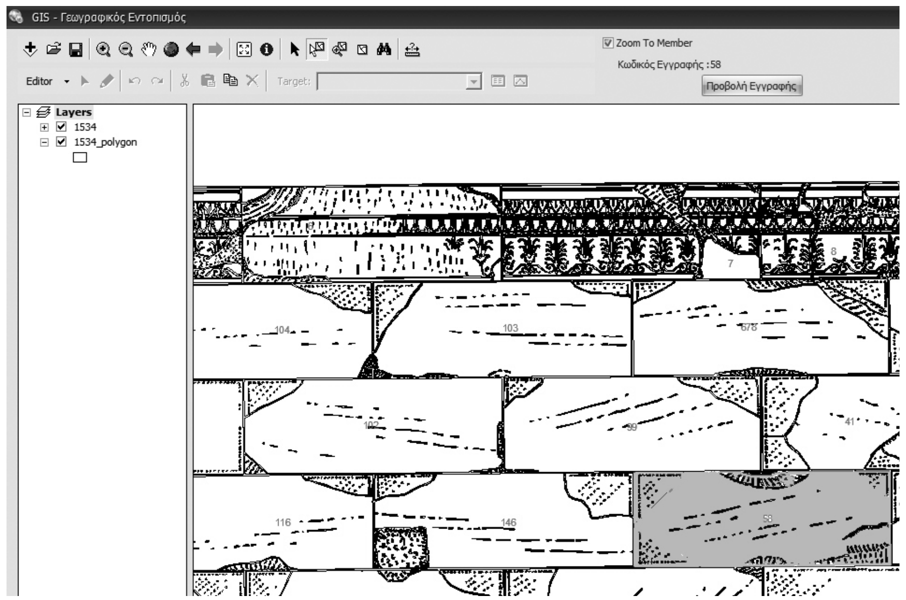
Fig. 6. The selection of block 58 of the south wall of the Erechtheion (2nd step)

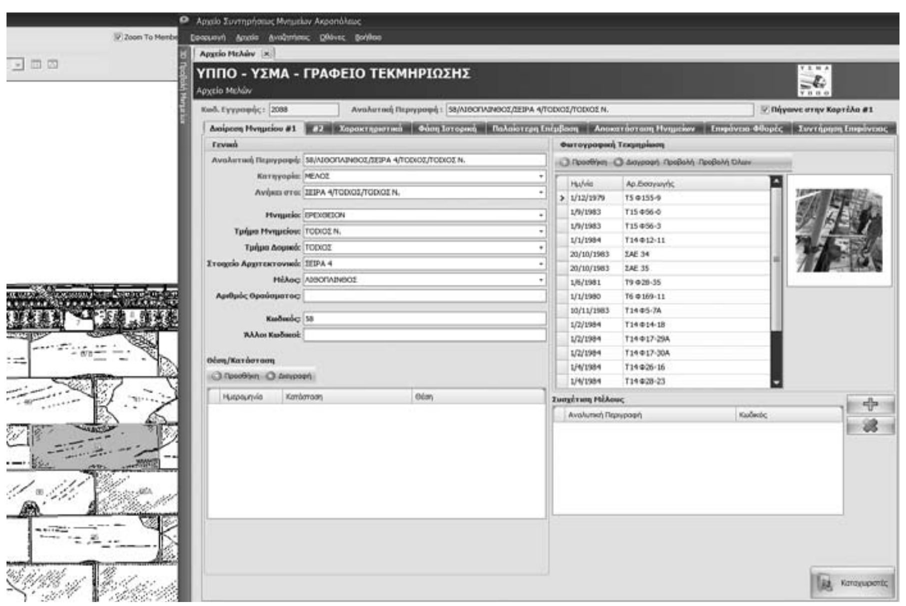
Fig.7. The entry of block 58 of the Erechtheion appears (3rd step)

of Crete as subcontractor for the database and especially the computer engineers who worked on the project, Michalis Papazoglou, Spelios Theodoropoulos, Alexandros Giannakidis and Yiorgos Papadakis. With Mr. Papadakis especially, we worked continuously to solve problems and to satisfy the needs that emerged.

In closing we would like to say that our immediate goal is to extend the use of the database to the sections of surface conservation in the worksites – a process already progressing. Also, the three-dimensional model of the Erechtheion through which the database is accessed will be replaced by a new model that has been made from three-dimensional scanning of the monument.

As medium perspectives –when the requirements in personnel and funding have been met– we consider the following:

• Loading the data from the circuit Walls into the database.

• Application of access to the other monuments through the three-dimensional environment, when the interventions on these have been completed. For example, the interventions on the Propylaia and on the north colonnade of the Parthenon have already been finished. And finally,

• application of Geographical Information Systems (GIS) to the monitoring of the position and movements of the members scattered on the Acropolis Rock.

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The subject of this presentation is the use of orthophotomosaics in architectural studies occasioned by their recent application to the general plan of the Acropolis and to the views of the west end of the Parthenon.

Reasonable questions such as the following are posed:

• What is new in the contribution of photogrammetric documentation to architectural studies for the restoration works?
• To what extent are they replacing conventional methods?
• How accurate are they?
• How economical are they in terms of time and money?

It is well known that surveys are a basic tool in the restoration of monuments, while precision in plotting is the most crucial element of their quality. Our knowledge about the form of the monument, its present and original geometry, possible deformations and structural disturbances, all are based on the survey plans. Moreover in carrying out the works of restoration, the survey plans are used for controlling repetition, saving the existing geometry and for restoring deformations in the course of resetting the dismantled structural members.

The earlier surveys, such as that of Penrose with its unsurpassable measurements and of Orlandos with their exhaustive extent, have determined the picture of the monuments we have today. With this in store, it was natural that questions of surveying and drawing very early occupied the ESMA. Professor M. Korres set the methodology that has for the most part been established for surveying the Acropolis monuments, especially the Parthenon. This comprises the degree of accuracy of the measurements, the choice of scale of drawing according to the purpose of the survey and the need for a common system of reference for the measurements. Thus, in the case of the Acropolis monuments, a high degree of accuracy was required in all procedures from the very beginning.

For this purpose, the means at our disposal will surely be pushed to their full extent.

In applying the new technologies, especially Orthophotography for surveying the Acropolis, the surface of the rock is recorded with the same degree of precision and detail over all. Whereas in the past surveys were individual, today for the first time a single digital model is created, which forms an operating platform for many applications. The main monuments and the smaller sanctuaries, the circuit Walls and the evidence for configurations and dedications in the precincts, are recorded on a single plan covering 29.000 square meters and their positions are plotted with great accuracy (to within about 3cm).

The new methods, enable us to carry out the survey by using the objective means of photography. Thus the plotting is controlled by clear specifications and secure objective criteria. Compared to the older surveys of the Acropolis, clear indeed are the advantages of this objective rendering, which

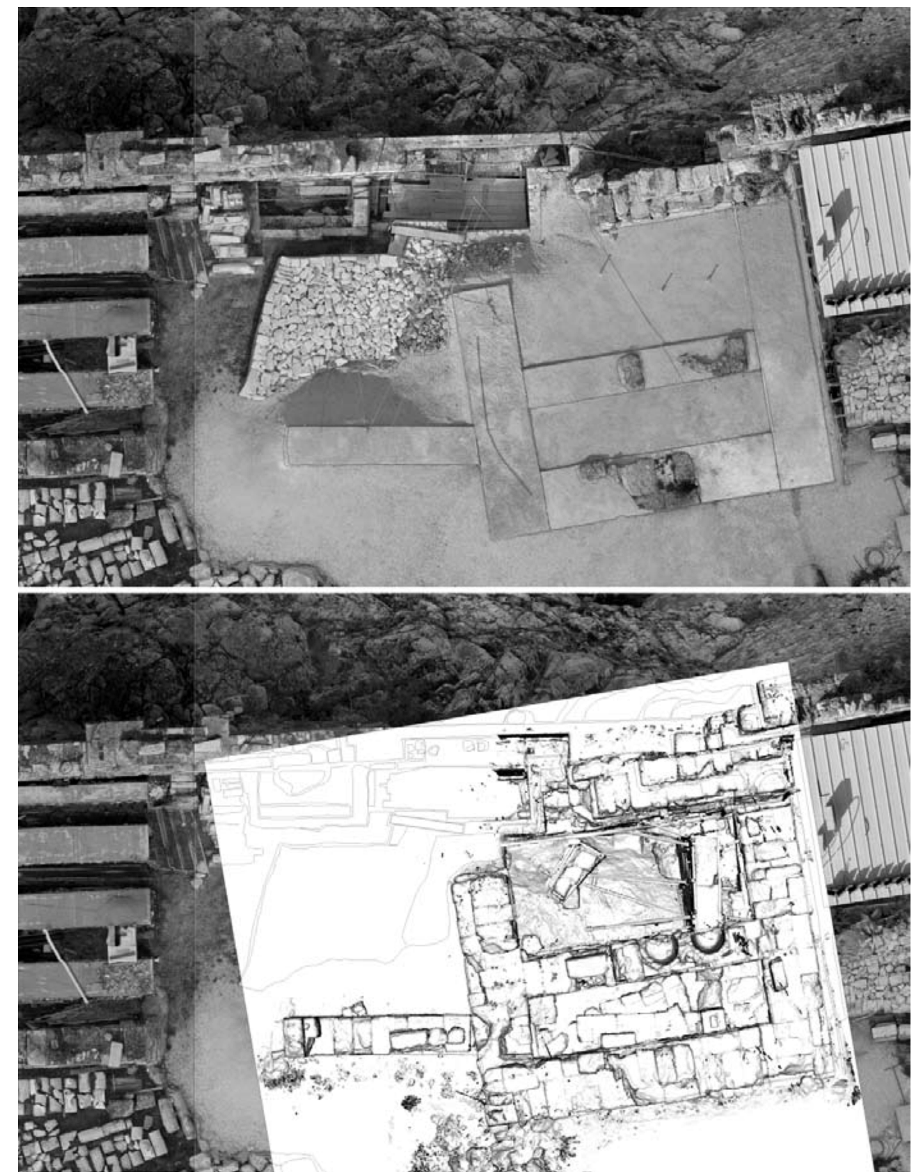
Fig. 1. The foundations of the Arrephorion after backfilling in 2007, in the photogrammetric documentation of the Acropolis (above). Three-dimensional scan before their backfilling and their inclusion in the photogrammetric plotting of the Acropolis (below)

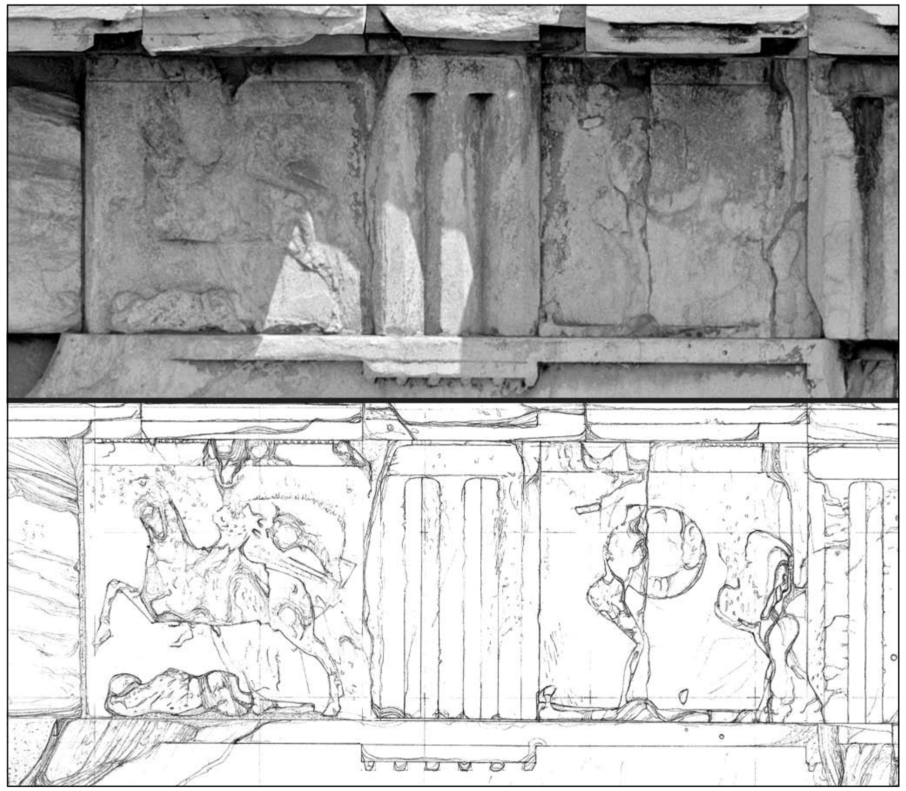

Fig. 2. The photomosaic of the west view as background in the architectural documentation for the recording of forms, such as the relief of the metopes, cracks and breaks in the marble. The figures show the 11th and 12th metopes of the west side of the Parthenon

is not affected by interpretation of the represented form. Formerly, whereas the measurement determination of the polygonometric points –the reference points on the rock– were satisfactory, the final plan was inconvenient and could not be utilised effectively. The critical difference is to be found in the interpreting of shades, since it is easy to misrepresent them when they are not recognisable. Thus, for example, during the topographical surveying of cuttings in the rock and small remains of foundations, they were omitted or registered as random configurations. On the other hand, in separate architectural surveys of areas of the Acropolis, where all the evidence was read in detail, it was not possible to attach them to a general ground plan - topographically. The new surveys of today offer an objective platform on which further research can be based – locally and as a whole.

We may note here that photogrammetric surveying does not replace conventional architectural drawing, on which the information is evaluated and studied depending on the purpose of the survey. The measurements are made directly from points considered suitable on the basis of examination on site, so that specific geometrical features can be identified and documented, and thus be more accurate. The measurements, the desired precision, the type of detail noted and the way in which it is rendered, depend on the aspect of the study on which we are focusing.

It is possible to enter the older survey plans, such as the Kawerau plans from the great excavation of the Acropolis (1885-1890), on the new precise photogrammetric plan. The advantage is significant, especially for areas no longer visible because they were backfilled after excavation. The site of the constructions and other remains that were found in the great excavation can be determined again with greater accuracy than in the past. The plans are appended on the basis of those parts of the remains that are still visible on the surface of the ground.

Digital surveying of the Acropolis allows continuous addition of data including that from recent backfills, such as the filling of the Arrephorion foundations in 2007. The remains of the monument, now invisible, can be set with precision by suspending all the documentary material from the area of the foundations that is still visible (fig. 1). For full documentation of the monuments prior to backfilling, in addition to graphic survey, three-dimensional scanning at a density of 0.5 to 1cm was carried out. Likewise full photography and topographical recording of all the surfaces was done using previously-marked points, that is, the necessary material was gathered for composing photogrammetric elevations and plans of all the foundations.

To determine the position of the underground remains, as well as the relief of the rock is exceedingly important for the archaeological, architectural and structural study of the Acropolis. It is useful also for designing various infrastructures for the restoration works. An example is provided by the bedding of the crane for the restoration of the west side of the Parthenon, west of the porch. Its secure foundation presupposes knowledge of the form of the rock, the extent of the fill and the possible presence of underground walls.

The common reference system allows the gradual addition of data and future plotting of parts of the areas of the monuments on which work is being carried out. For example, in the Parthenon north colonnade, the resetting of each course of the blocks of the entablature is followed by photography and surveying with predetermined targets.

In addition to information about the geometry of the blocks, the orthophotomosaic includes an abundance of other supplementary information, such as cracks, damage of all kinds, the texture of the material or the type of erosion suffered by the surface. Since additional time is not necessary for its recording, it is of great help in reducing work in the open. For example, the architectural survey of the west end was used as a platform for recording forms, such as the relief of the metopes, cracks and breaks in the marble (fig. 2).

The benefit of the new technologies clearly lies in the plotting of the views of the monument to which there is no access; for scaffolding does not need to be erected thus avoiding aesthetic interference, and lowering operating costs. Moreover, so as to survey the Walls, the extent of which prohibits conventional methods, the application of photogrammetry by-passes intrinsic problems.

Yet requirements for the extreme accuracy of measurement and drawing, sought for the Acropolis monuments, demand attention to the following points:

• For the entering of data into a common reference system to work, the correct choices have to be made at the very beginning (fig. 3). As for the plans, the projection level of the points is horizontal and therefore given. For elevations, however, suitable revolution points for the sighting level must be chosen so that it is parallel to the basic lines of the monument or, in other words, in order to include it in the best way in the common reference system.

• The choice of points to be measured for producing an orthophotomosaic is based on criteria that are different from those used for the points measured in a topographical survey. Yet their combination is desirable. For this purpose the use of predetermined points is preferable. This ensures more accurate measurements (the points are clearly defined and avoids the absorption of laser rays by the marble, which can alter the measurements, fig. 4). For greater assurance of the measurements we believe characteristic points of the surfaces of the marble, which are worth recording in the course of measuring, should also be included.

• The question of the degree of accuracy of the products of photogrammetry is, indeed, paramount. We will present an example from the west side of the Parthenon. Photomosaics were made of the exterior and interior views of the entablature, together with measurements by conventional means in order to determine the geometry of the architectural members. A comparison of the photomosaic of the exterior view, scale 1:20, with the corresponding linear plan of the cad archive, shows that the deviations in the measurements are within the limits of accuracy of drawing that were established from the beginning, 5.5mm (fig. 5). On the interior view, the horizontal precision of the photomosaic is controlled in a more direct way, since there the measurements were made on predetermined points. The deviations here are in the range of 2mm, which was the degree of accuracy designed for a scale of 1:10.

In order to determine the horizonal curvature of the interior view of the entablature, depth measurements were made in respect to the vertical level, at specific points using a theodolite. Although completion of the three-dimensional model is expected after the ground-plan of the west side has been processed, comparison (fig. 6) of the elevations of the model of the interior view with our measurements has shown deviations that are satisfactorily minute, up to 3mm in 12 monitored places.

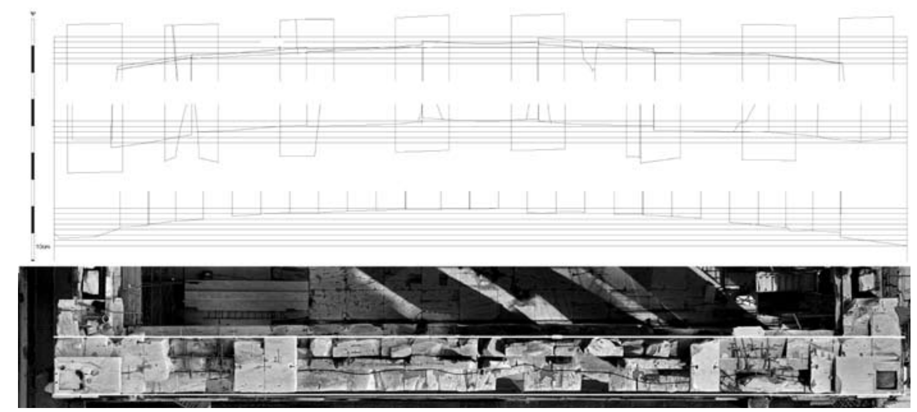

Fig. 3. Plan of the west side of the Parthenon. The deformations are rendered in elevation on the plan (above). Marked on the plan (below) are the levels of projection for drawing the views, which are determined in relation to the very firm stylobate

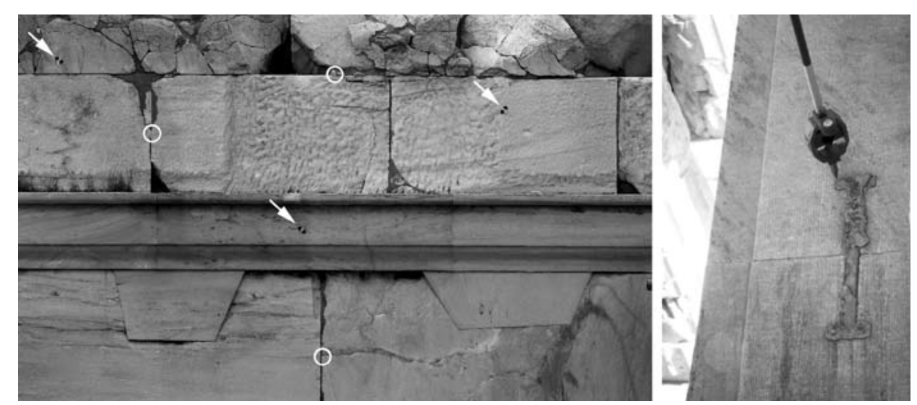

Fig. 4. Use of predetermined targets (indicated with arrow) and characteristic points (encircled) in the photogrammetric plotting of the inner side of the Parthenon west porch

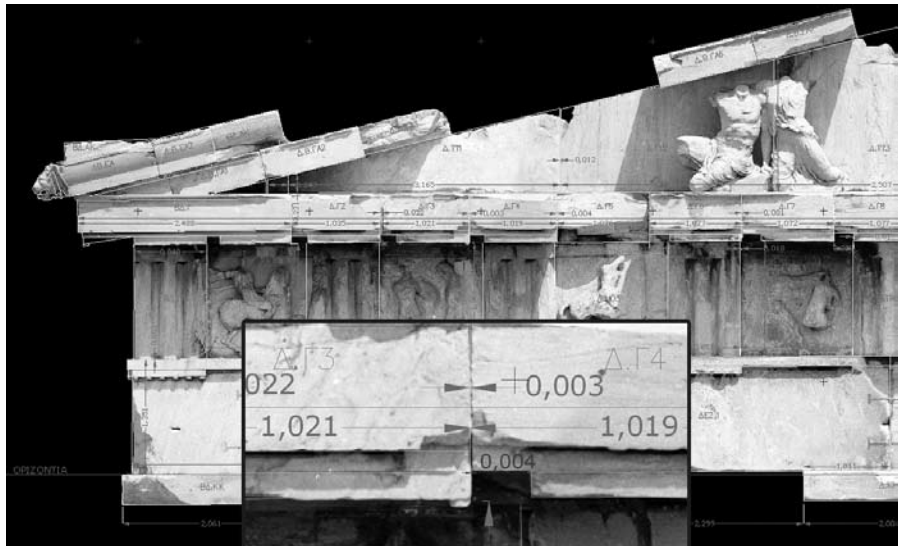

Fig. 5. North part of the west view of the Parthenon. Collation of the photomosaic of the exterior view (scale 1:20) with the corresponding linear drawing cad. Deviations at measurements 3 and 4mm are noted

• In connection with matters of precision, perhaps it is not superfluous to keep in mind that, despite the possibilities offered by advanced technology for plotting at a scale of 1:1, this always depends on the precision of the measuring equipment and on accuracy in processing the orthophotomosaic.

• A significant factor in the choices made is the time required to process the digital models. The procedure itself is time-consuming enough and the time needed greatly increases in relation to the degree of accuracy required. As an example we may note that the digital model of the interior view of the entablature of the west side (scale 1:10) took 1 month's work in the open and 5 months' work in the office.

• Thus the question of the hierarchy of the needs of each work is shown, in order to choose the areas or sections of the monuments that it is advisable to map photogrammetrically and at which scale.

Conclusions

1. Photogrammetric surveys form a reliable, objective and usable platform with uniform accuracy throughout, for entering earlier, recent and future surveys, both conventional and digital.
2. They provide an unbeatable solution to plotting, at a large scale, surfaces covering many square meters with strong relief, to which there is no approach.
3. They do not replace, but they supplement conventional methods of architectural surveying.
4. Prerequisites are advanced technological equipment and specialised scientific personnel, and these require time and money.
5. The usefulness of their application must be evaluated for each separate case.

Finally, we must emphasise the importance of all involved collaborating at every stage of the process, whether during topographical recording or in the course of processing the digital model. Full comprehension of the object by all those involved is required. Collaboration of the topographer preparing the digital model with the architect-researcher is a necessary prerequisite for forming common parameters that will yield better utilisation of modern survey tools.

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Architect Engineers
Work of Restoration of the Parthenon
YSMA

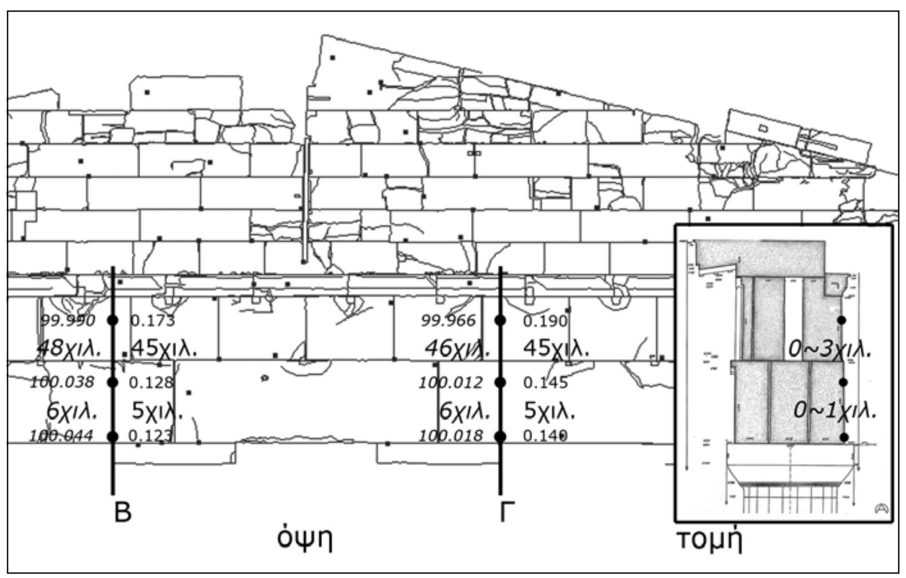

Fig. 6. Interior view of the west side of the Parthenon. Collation of background measurements in the photogrammetric model (scale 1:10) and direct survey with theodolite. The first are registered left of the positions of the measurements and the second right. Deviations of 1 to 3mm are noted

All illustrations are included in the "Study for the restoration of the west side of the Parthenon" by V. Eleftheriou. V. Manidaki and A. Vrouva.

The deployment of an accelerographic array on the Acropolis hill area: Implementation and future prospects

Introduction

It is well known that the broader Aegean area is characterised by high seismicity that affects the variety of building stock. The construction type is classed as an important issue concerning the extent of damage, amongst other parameters that also contribute even further (i.e. seismic source properties, propagation path of the seismic waves, local soil conditions). The seismic resistance code covers a wide span of common everyday constructions, while the important types (i.e. dams, bridges etc) are constructed following an obligatory seismic hazard study. The archaeological sites and their monuments are also a special case, since they were built in the past, with the technological knowledge of their era. Moreover, they have suffered more or less a number of strong earthquakes, as well as human interventions (catastrophic or consolidating). In addition, archaeological sites are visited, particularly in the summer and some of them throughout the year, by a significant number of visitors, resulting in some cases to significant crowds (as for example on the Acropolis hill site), where emergency measures have to be taken, especially in cases of a possible natural hazard incident.

Taking into account the importance of the above mentioned aspects, the Institute of Geodynamics of the National Observatory of Athens (IG-NOA) and the Acropolis Restoration Service (YSMA) started a collaboration in the year 2006, with the deployment and permanent operation of a free-field accelerograph on the Acropolis hill and discussions of further plans for the deployment of a permanent accelerographic array in order to record strong ground motions, for the study of the effects of local factors and more over their effects on the monuments.

The Acropolis hill is a limestone block of Upper Cretaceous age that rests on the Athenian schist rock series [1, 7]. This formation is similar as for the other hills in the city of Athens (i.e. Lykabettos, Philopappos). Cracks with great inclination have fragmented the limestone. In order to develop a horizontal level for building construction on the top of the hill, some parts of the rock have been filled artificially with earth material up to 14m of thickness.

On the Acropolis hill the Athenian schist is visible at the site of the main entrance up to the Propylaia, whereas the Upper Cretaceous limestone, greyish in color, is exposed on the top of the hill. Erosion of the limestone has created caves and fissures, which are visible mainly in the NW and S slopes, but also evident in the hill interior. Springs have emerged at the base of the hill, where the contact between the permeable limestone and the impermeable schist exists (i.e. Klepsydra at the NW).

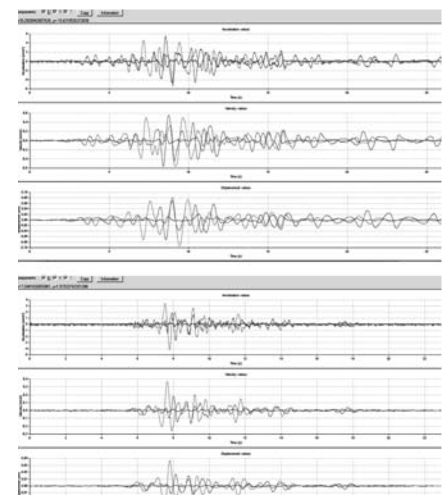

Fig. 1. Time-histories of ground acceleration, velocity and displacement for the earthquakes of Andravida (above) and Mantoudi (below)

In general, instrumental seismic monitoring of an important site is one of the most significant steps within the conservation of cultural heritage, since it is connected with recognition of probable, potential hazards and thus it is important for determining measures of protection. The development of a Geographical Information System is necessary to serve as a platform to incorporate all the available data for complete documentation of the site of interest and in order to make easily available the information to scientists of different fields (i.e. UNESCO, ICOMOS).

Deployment of the accelerographic network

Following the interest expressed by YSMA, IG-NOA deployed a digital 12-bit accelerograph on the Acropolis hill. The site selection (at the limestone appearance) was made with the collaboration of the YSMA staff, while the infrastructure preparation was done by the YSMA (small vault con-

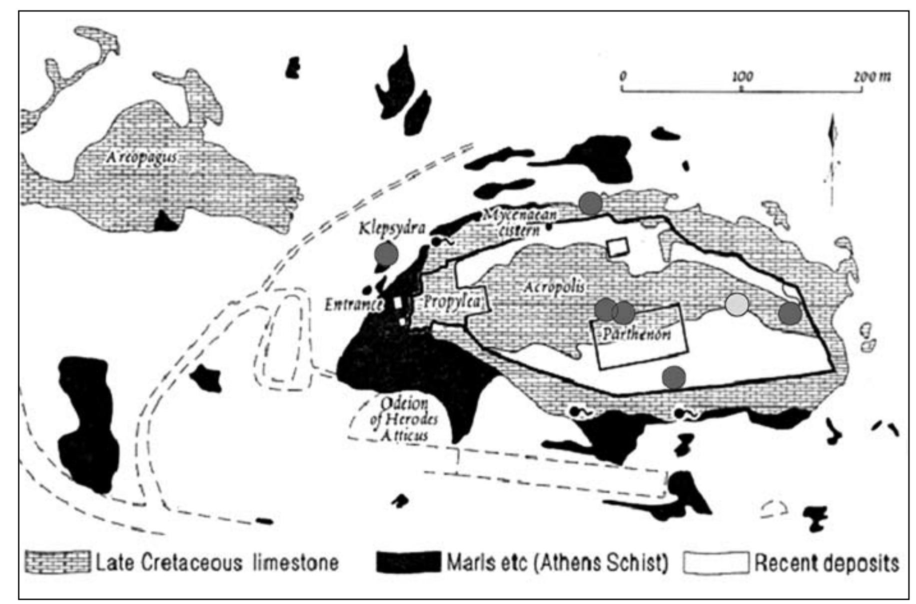

Fig. 2. Geological sketch of the Acropolis hill (by Higgins and Higgins, 1996), showing the installation sites of the accelerographs. The light grey circle indicates the first accelerograph installed in 2006, the dark grey circles show the positions of the new accelerographs installed by the end of 2008

struction for the instrument deployment, supply of power and communication network). The accelerograph was connected via the Public Sector Network "SYZEFXIS", in order to monitor the state of health of the instrument operation and to retrieve recorded strong ground acceleration waveform data at the Seismic Monitoring Centre of IG-NOA in Thissio. This arrangement succeeded with the first records of seismic events ever recorded on the Acropolis hill. More specifically, two seismic events were recorded, the one of Andravida, Achaia/Elia (8/6/2008, M=6.5, epicentral distance 195km, PGA=0.006g) and the second of Mantoudi, Evia (14/10/2008, M=5.6, epicentral distance 100km, PGA=0.004g). Although the recorded peak values of the strong ground motion were especially low, it is of great importance the fact that an accelerographic instrument of low resolution was triggered by earthquakes of moderate size from long epicentral distances. Fig. 1 shows the corresponding time histories of the ground acceleration, velocity and displacement for the three components of the accelerograph, respectively.

Since 2008, IG-NOA was contracted by YSMA to carry out the project "Deployment of an Accelerographic Array in the Acropolis Hill Area". Within the planned project framework, five digital 24-bit accelerographs of the latest technology were purchased. In co-operation with the YSMA personnel, six sites were selected for instrument deployment, succeeding to cover variety of local characteristics: a site on the Athenian schist (geological bedrock), a site on the limestone at the base of the north Wall, a site on the east side of the hill (on limestone next to the Wall), a site on the south side of the hill (where there is the thickest part of the artificial earth filling), a site at the foot of one of the Parthenon columns and the respective site on the architrave. Figure 2 presents a geological sketch showing the sites of deployment with dark grey filled circles, while the light grey circle marks the location of the first deployed with 12-bit resolution accelerograph.

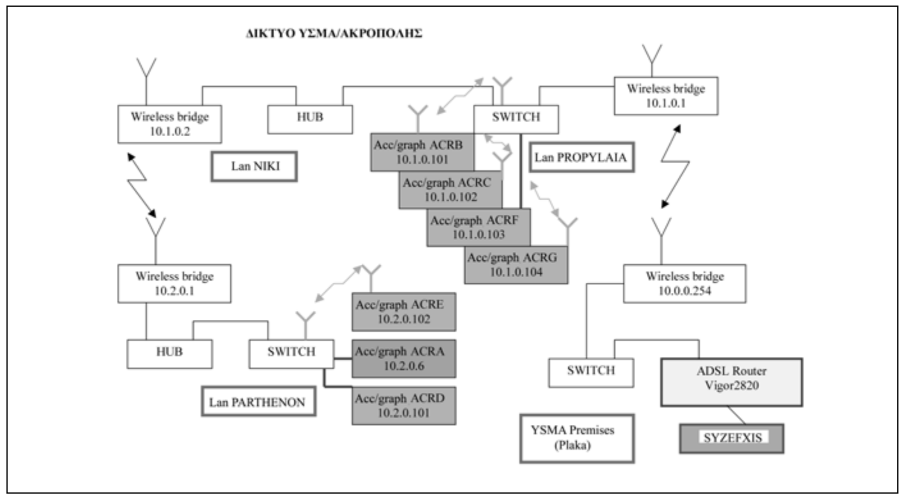

Fig. 3. Schematic representation of the Acropolis computer network with the incorporation of the accelerographs for their monitoring and data transmission

Fig. 4. The equipment at the installation sites and the final picture of the installation sites with the protective box covering all the equipment

A small vault was constructed at each location with available power supply. Access to wired LAN communication network was necessary at only two of the six sites, as it was decided to use wireless (wi-fi) connection to the corresponding available LAN network of YSMA. Figure 3 provides a schematic presentation of the network interconnection with the accelerographs incorporated. In particular, for the two accelerographs at Parthenon, the foundation of the instruments was succeeded without a vault construction, and the specific column was chosen in order to include new members on which all the infrastructure would been fixed.

Various factors were taken into account for the installation of each instrument, mainly to avoid as much as possible the interference upon the monuments and the public and to protect the equipment from the difficult weather conditions that prevail (for example, protection against lightning strikes, supply of 12V DC to the instrument sites, etc).

In certain cases, techniques were applied to limit the wiring used (for example PoE), while special care was devoted to the wireless equipment (limiting the signal, communication security, etc). The infrastructure at each location includes the accelerograph, the

power box of 12V DC supply, the absolute timing unit (GPS), the lightning protector and the antenna used for wireless transmission. At selected sites the referencing access points (antennas) have been placed, as well as the power supply of 220V AC with surge protector and a fuse. Figure 4 shows an example of the basic infrastructure that is covered by a small protective box. The component orientation of all the accelerographs is set to X(+)N0°, Y(+)N90°.

The band of the wireless connection was chosen in the range of 5 GHz rather than in 2.4 GHz, in order to achieve undisturbed communication, while security is provided: a) on the physical level (directional antennas, careful limitation of signal strength and limitation of broadcasting), b) on the level of data linkage (MAC filtering, use of ESSID, use of a code security mechanism - WPA2), c) on the level of network and data transmission (IP Filtering and NAT). In addition, the equipment was chosen in such a way to function not only as a communication bridge, but as a router too, in order to assure greater flexibility and security.

For the data collection system, a computer server was installed at YSMA premises at Plaka. It was set up to have direct link with each of the instruments independently, whether they were connected through the wireless links or else. A suitable software was installed centrally that takes care on the following: a) monitors the operational status (state of health) of each instrument and gives the opportunity to the user to adjust various instrument configuration parameters, b) records data on real time from each instrument, c) stores the data on the computer disk, d) sends the data to other institutions, e) it is able to send warning signals to various users. Nevertheless, the accelerographs, due to their construction and the use of the communication network "SYZEFXIS" by both the partners, can be monitored at the IG-NOA premises as well.

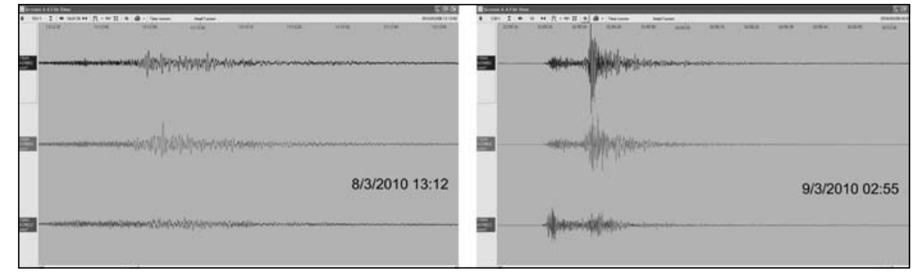

Fig. 5. Records from the Efpalion (8/3/2010) and the northern Evia (9/3/2010) earthquakes obtained by the accelerograph installed at the foot of a Parthenon's column. At that time the accelerograph had not yet been installed on the architrave due to restoration works

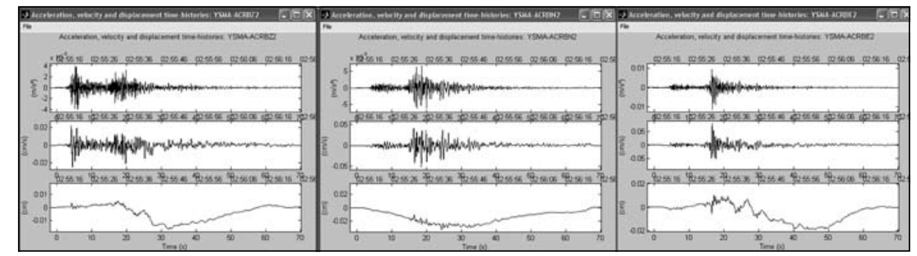

Fig. 6. An example of ground acceleration, velocity and displacement time histories from record processing using software ART 3.0 [5], without the use of filters, for the three components (Z, N, E)

Array parameterisation and first recordings

The parameterisation of instruments is the most important function for resulting a reliable operation of a new accelerographic array, given that it is necessary to take into account various factors concerning the characteristics of the instruments (available memory, continuous recording or recording according to triggering threshold or according to the level of the value of the STA/LTA ratio, transmission of data or transmission and simultaneous recording in the internal storage medium, the circular use of memory with overwriting the older recordings), the characteristics of the sites for installation (for the Acropolis hill site case: substantial level of noise from heavy machinery or from the works of monument restoration, extreme weather conditions, quality of communication) and the aims of the array deployment. During the first stage of operation, the parameterisation of the instruments passes trial stages in order to obtain the best combination to improve their operation. Although the array passes through the first stage of operation, it is worth mentioning the recordings of series of earthquakes. Among them, the two most important were: the one from Efpalion area (8/3/2010, 13:12, 38.38N 22.09E, h=15km, M=4.2) and the other from the Northern Evia area (9/3/2010, 02:55, 38.87N 23.65E, h=22km, M=5.1).

The obtained records correspond to earthquakes occurred at the broader area of the western Corinth gulf and at northern Evia area. In this particular case, however, the earthquakes were weaker than those of the year 2008, the 12-bit accelerograph was not triggered (thus did not record these earthquakes), and the recordings were extracted from the continuous recording files with the peak values of ground acceleration ranging from 0,0001m/s^2 to 0,011m/s^2. Figure 5 shows the recordings of the afore-mentioned earthquakes for the three components of the accelerograph installed at the foot of a Parthenon column (ACRB), while figures 6 and 7 show the time-histories of the ground acceleration, velocity and displacement, as well as the response and Fourier spectra respectively, as output examples from the processing procedure using the software of the deployed instruments manufacturer [5], without the use of frequency filters, for the earthquake of 9/3/2010 02:55.

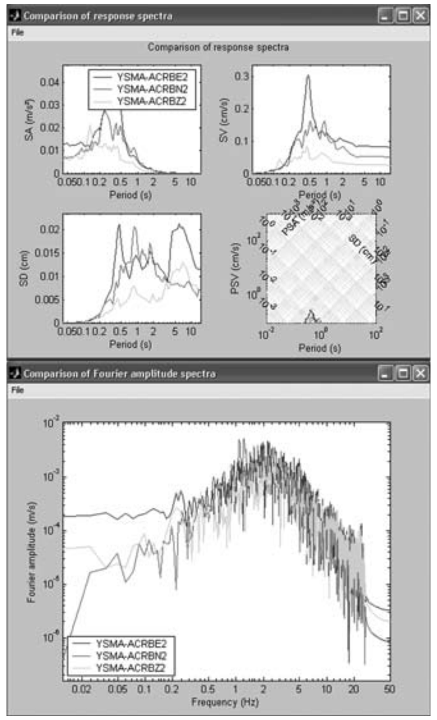

Fig. 7. Examples of response and Fourier spectra from record processing using the software ART 3.0 [5], without the use of filters and for damping factor 5% for the three components (Z, N, E).

Other activities in the framework of the present project

1. Training of the YSMA personnel: Within the context of the work, the IG-NOA organised seminars with instructions concerning the methodology of the accelerographic network installation and operation for selected members of the YSMA staff based on the following subjects: a) Seismology - basic concepts, b) Engineering Seismology - basic concepts, c) Accelerographs - accelerographic networks, d) Processing of accelerograph records, e) Examples of accelerograph records processing, f) Strong ground motion databases, g) The Acropolis Accelerographic Array - communication support.

2. Study of seismic hazard: In the framework of the project YSMA was given a special volume on the study of seismic hazard of the area. This was followed by the usual process of computing the seismic hazard, which comprises of the following steps: a) determination of seismic sources, b) determination of seismic activity after the calculation of parameters a and b for the area, c) selection of the relation of attenuation of the parameters of the strong ground motion (macroseismic intensities or strong ground accelerations and d) probable evaluation of the final value of the strong ground motion as a function of the previous defined parameters. Estimated in the study of seismic hazard were the average values of horizontal seismic acceleration and velocity that are expected not to be exceeded in the Acropolis area in a repeat period of 72 years (a 70% probability of not being exceeded in 25 years), 475 years (90% probability of not being exceeded in 50 years), and 949 years (90% probability of not being exceeded in 100 years):

A_{72}=0.14g V_{72}=9.0cm/s
A_{475}=0.22g V_{475}=13.0cm/s
A_{949}=0.30g V_{949}=27.0cm/s

Corresponding earthquake scenario considered:
1st model: R=10km, M=6.0, h=8.0km
2nd model: R=40km, M=6.5, h=10km
3rd model: R=100km, M=7.5, h=10km

Perspective of the accelerographic array on the Acropolis hill

After the final installation of the accelerograph on the Parthenon architrave and the installation of one more accelerograph at the eastern side of the hill (exposed limestone close to the wall), at present the array consists of seven accelerographs connected online.

The IG-NOA continues to support the network after the contract ended, by collecting and processing the data and continuing the maintenance of instruments within the framework of the National Accelerographic Network. The main target is to limit functional failures, either through inspections at the site when it is required for repair, or by upgrade accordingly to the infrastructure or the software. The recordings are processed and increase the relevant maintained database. A proposal has already been submitted to YSMA for the expansion of the array, by increasing the radius of the network and the density of the existing deployment. The instrumentation of other specific points at the Parthenon or at other Acropolis monuments is of great interest for both sides, given the topographical and other local site differences, as well as the installation of instruments at the broader area around the Acropolis hill, where the Athenian schist or other soil formations are exposed (i.e. the Ancient Agora). Data collected from the broader area, could be used by scientists involved in the restoration and conservation of the monuments.

The full documentation of the sites of the array and the comparison between information extracted from it with other information having a geographical component of the Acropolis area in a single scientific database, within the framework of a geographical information system is also proposed. Under this point of view a broader decision making system could aim to the estimation of hazard zones (buffer zones) around the monuments for protecting the public in case of significant seismic event.

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Instrumented strain monitoring of the Acropolis Wall with optical fibre sensors: Comparison of the measurements to the analytical predictions

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English translation by the authors

Introduction

The circuit Wall of the Acropolis was built in different stages from the Classical to the Ottoman period. In the course of time it has been damaged, primarily by the action of the natural environment and by human interventions. Numerous earthquakes, sieges, its various uses through the long history of the Acropolis, and also constructional defects connected with the structure's aging, have produced visible cracks that pose danger in the form of structural failure of the monument.

Specifically, in many areas of the Wall there are extensive cracks that are more numerous towards the end of the southeast corner of the Wall. It is not clear, in the beginning, if they can have a decisive effect on the structural behaviour or lead to structural failure.

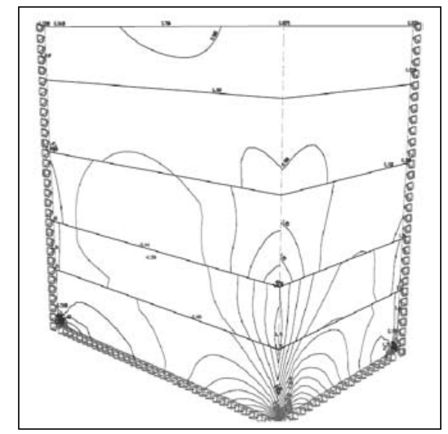


Fig. 1. Preliminary structural analysis of the SE corner of the Wall (isolines for tension and compression)

In the context of researching the structural behaviour of the Wall –among other things– the Acropolis Restoration Service (YSMA) of the Ministry of Culture and Tourism (YPPOT) implemented a pilot system for instrumental monitoring of the Wall. The system comprises deformation sensors with optical fibres of Bragg Gratings type, which have been set at chosen positions. These have been chosen specifically in order to monitor any widening of the cracks that already exist. The optical fibre sensors are incorporated into special rods of about one meter in length. Their positions and orientations are chosen so they can monitor the strain field at the end of the crack, or bridge the cracks and monitor their openings.

The specific application of the sensors that is presented here has the special feature of being able to combine the ad hoc adaptation of the sensors to the substratum and the troublesome work of interpretation and diagnosis of the pathology of the Wall with the help of the sensors, despite the relative limitations imposed by the monumental aspect of the Wall.

Principles of structural monitoring

Monitoring the structural integrity of buildings (Structural Health Monitoring) is a

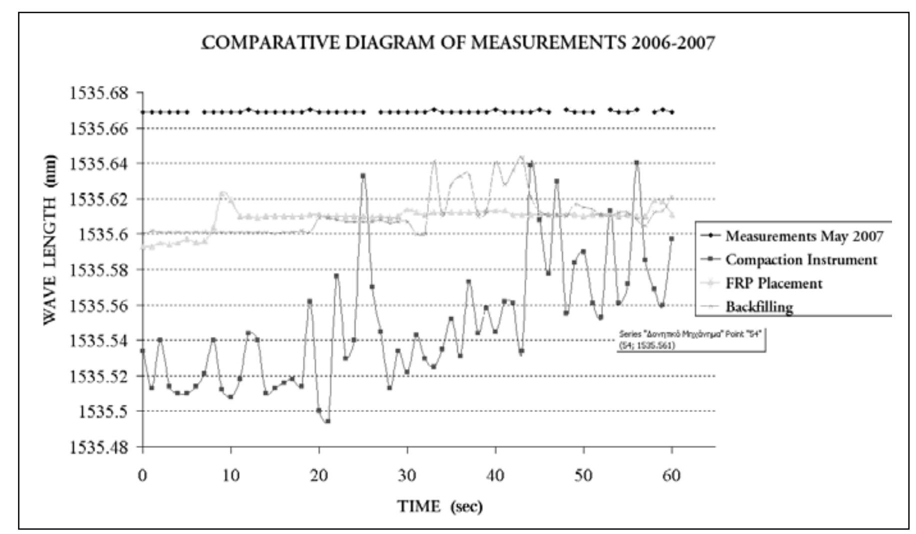


Fig. 2. Comparative diagram of measurements 2006-2007 [wave length (nm)-per unit of time (sec)]

new scientific field. Its purpose is to provide, to the extent possible, reliable data about the condition of the entity being monitored (existence of defects, faults, stress, degree of emergency etc.), in order to decide about its further use, or its repair in the most suitable way. In general, it is considered to be the work of the Engineer to solve a converse problem. Knowing, probably, the adjacent conditions, despite the precise record of the entity's inflexibility, he tries to determine the structural properties of the construction and to locate any possible mechanical discontinuities. For these purposes, reliable but inexpensive sensors are used that are set into critical areas of the construction (for example gathering areas/stress trends, areas with the greatest deformations, etc.) and areas which have data related to its behaviour while under functional load. A comparison of these data with the standard behaviour of the construction (according to the results of simulation and of other calculations made during the design phase) provides the possibility of "continuous diagnosis" of its structural integrity and the discovery of chance structural failure or malfunction.

Principles of choosing the type of sensor and site of application

This is usually accomplished through the detailed calculation and comparison of the expected (initial) behaviour of the construction and by locating its "sensitive areas". The type of sensor to be used depends also on the kind of area to be measured, the accuracy desired and the operating environment. The best available form of complex sensor is one that can be installed and removed as needed, and can yield a much better description of the elastic line of the bearer. In the case of the Acropolis circuit Wall, the use of this kind of sensor is obligatory since the uneven surface of the stone masonry does not permit any type of pasting. The main problem, however, is the nature of the stone construction, which is not an homogenous and isotropic entity that would allow sensors of small length to be set. Long gauge sensors are as a rule less accurate, but they are ideal for works of a monumental nature, such as the masonry of the Wall. With them, the research effort is to measure deformations (and accompanying tendencies) in front of the ends of the cracks and discontinuities and to explore the curvature of the Wall as a bending body, despite all the anomalies and protuberances there may be.

Proposed for this research and finally chosen were sensors with optical fibres of Bragg Gratings type.

The circuit Wall of the Athenian Acropolis

Generally speaking, this is an extraordinarily complex construction, the measurements of which are not known throughout. The height of the wall ranges from around 15m to 22m and the thickness from approximately 6m at the base to 1.0-1.5m at the crown. For the needs of the pilot study, it was decided that its behaviour corresponds to a section of the thickness of the shell. With the course of the works and measurements already accomplished or under way, the best way to simulate the structure would become to a great extent evident.

The loads that are considered to affect the Wall in the current pilot application are the following:

• Gravity loads.
• Earth pressure.
• Hydrostatic pressure.
• Differential settlements.
• Thermal loads.
• Strain compulsions due mainly to temperature changes.
• Seismic actions.

Fig. 3. East Wall. Position of the sensors on the Wall

The activity of the cracks, and their expected expansion are of basic interest for the research, which is carried out with sensors, but also with extensive arithmo-analytical investigations using the theory of finite data. Apart, however, from the cracks that have formed or are in the process of developing, there are important questions about the entire structural behaviour of the Wall, and efforts are made to answer them:

• Elastic or non-linear simulation parameters. In order to form a reliable model logical assumptions have to be made about the elastic or non-linear analysis.
• Cohesion of the Wall. For example, the question arises as to whether there are parts of the Wall that function as solid-undistorted entities having little consistency with the rest of the Wall, which, generally, conforms to the statutory relations of elasticity.
• The type of loads to which it is subjected and which of these are critical and to what degree. Which of the loads subject the Wall to dangerous phenomena.

Monitoring of the structural behaviour of the Acropolis circuit Wall

For research on the above questions and to deal with the cracks that have developed, methods of monitoring the structural independence are mustered. The positions for applying and setting the sensors are found through topographical plotting of high precision.

In each series of sensors, the last one has a temperature gauge. A total of 124 sensors were set.

Because of the appearance of the cracks vertically, especially close to the corner of the

juncture of the south-east Wall, it was decided that it would be preferable to set the sensors in a horizontal arrangement.

• Taking measurements from the sensors.

The measurements were made at regular time intervals in order to include sense hydrostatic impulses, temperature changes and so forth. In general the seasonal change of the deformations was considered to be a significant load and agent of damage over a long span of time.

• Comparison of the measurements with the initial measurement.

In this phase it is necessary to combine all the theoretical and experimental data, in order to evaluate the experimental results for locating the faults precisely. The main inspection at this stage will be comparison of the elongation on the two sides of the sensor.

• Enaction of danger and alarm limits.

In the study of the behaviour of the Wall significant changes in its deformative behaviour are to be expected. Study of the loads will yield limits for warning and danger. For example the hydrostatic impulses after a strong downpour will lead to local maxima, which must always be monitored in similar situations.

In practice, an initial measurement is usually made immediately after the monitors are set. The initial measurement provides the "reference measurement", with which later measurements are compared in order to determine if further analysis of the results is needed for reaching conclusions about the monument's structural integrity.

It should be noted that the south side of the Wall suffers from serious thermal loading. This became evident during the inspection and in the process of consolidation.

Description of the optical fibre sensors and theoretical principles of the calculations

For organising the system on the Wall a commercial type of optical sensor was used, known as Bragg Gratings, which were incorporated in rods of composite materials (smart rods®). The Bragg Gratings sensors that are incorporated in part of the rod function in bands of 1520-1570nm and they are sensitive to change in the mechanical field and that of temperature. The presumed change of wave length of the sensor is measured by a special recording machine.

The smart rod is made of a material of poltruded polymer type. It thus has great resistance to corrosion and the sensors are compatible with surface securing to the Wall. It should be emphasised that the optical fibres are totally resistant to the impact of electromagnetic rays (EMI/EMC) and are suitable for use in long-term monitoring of structural integrity, given that they yield trustworthy measurements, without any decline in precision or need for periodic calibration. Finally, these sensors can be used either separately or as part of a series in an optical fibre, the greatest number of sensors being determined, mainly, by the optical demodulator.

The amount of load is determined from the measurement of the deformations in situ.

The plotting of the cracks showed that the behaviour of the Wall is probably similar to that of plane stress, where the south and east part of the Wall near the dihedral angle meet. This is the main parameter for the choice of relative disposition of the sensors horizontally rather than vertically.

Yet for the off-level bend, it must be said that this section of the Wall functions as a

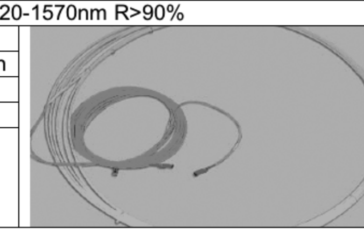
Resolution capability	0.2 pm	*Wave length*
	0.2 μstrain	*Deformation*
	0.02 °C	*Temperature*
Optical cable	Diameter 3mm Protection PVC – KEVLAR Fibres	
Type of optical fibre	Monotropy 9/125μm - Acrylic sheathing 250μm	
Type of sensor	Wave length 1520-1570nm R>90%	
Length of sensor	0.1 – 10mm	
Measurement span	± 20.000 μstrain	
Optical link	FC/APC	
Source of electrical power	-	
Operating temperature range	-100 to 300 °C	

Table 1. Smart Rod® sensor basic technical data

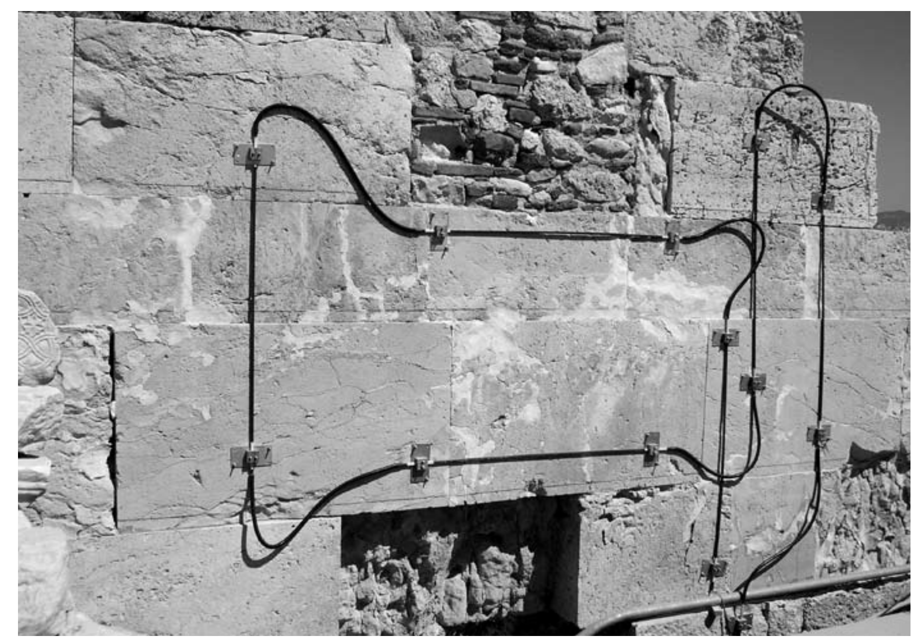


Fig. 4. North Wall. Position of the sensors on the interior of the Wall

supporting wall and expected also is the limit of axial force to the thickness, which can be considerable.
The radius of curvature (in horizontal or vertical arrangement) depends on the deformation. Setting two sensors per smart rod on two different channels (optical fibres) will verify the application of this relationship. The feature of the sensors that is absolutely necessary for this application is of course the system's excellent precision and power of resolution, which reaches the level of one μstrain.
In addition to the above, it will be possible also to determine the curve of the smart rod in section at the position of the sensor when we know the deformations at its two antimetrical outermost optical fibres.

Works of consolidation

The works of consolidation were carried out so that the structural integrity of the Wall was not disturbed, even minimally. While the basic goal is to monitor the main cracks and the main groups of cracks, the sensors were set so as to avoid disturbing the area of interest almost entirely except, perhaps, for the area directly beneath the anchoring slab. This is how the sensors are set on the exterior face of the Wall. They are anchored with bolts and stainless steel. Each sensor is consolidated separately with two anchor slabs and stainless steel anchors.
The outer surface of the east Wall, moreover, was found to have a significant curve outwards. A great effort was made to cover the curve with smart rods. In this case the specific sensor showed its extraordinary adaptability; since it is flexible it could "follow" the relief of the outer face of the Wall.

South Wall

The south Wall varies in thickness between 5-6m at the base and 1.0-1.5m at the crown, with the height of the Wall ranging from 10m to 20m. Four series of smart rods were set on the south Wall. In the area close to the edge of the south-east Wall, three series were placed and one series after the embankment. The three series comprise one series high on the top of the Wall with seven smart rods, one series of five sensors at about the middle and one series of seven smart rods at the foot.

North Wall

The thickness of the north Wall varies from around 1-2m at the base to 0.5-1m at the crown. The part of the Wall under study ranges in height between 4m and 6m. Two series of smart rods were set on the north Wall. One series of seven sensors on the interior of the Wall and one series of five sensors on the outer part, on the crown, and a single smart rod with four sensors continuing the series. On the exterior face of the Wall the sensors are distributed so as to monitor the free edge of the Wall. On the innerside the sensors are set so as to monitor the change in slope of the Wall in the best possible way. The topographical plotting made in the context of this work showed that there was a slope of 7° in this place. By monitoring this location, it is expected that the Service can identify the affect of the loads of marble piled up at this position and what dangers may exist. We note here that the eccentricity that has been observed is considered to be particularly dangerous, mainly in seismic phenomena.

Fig. 5. End of sensor anchored near a crack

Measurements

Before being installed on the Wall the sensors were tested to ascertain their correct functioning, to check their recognition in the operating system as a whole and to verify the wave length.
The diagrams prepared are drawn from measurement tables to which new measurements can easily be added so that corresponding diagrams receive information automatically. From the development of these diagrams the response of the Wall will be diagnosed with the help of comparisons with finite data. Needed likewise for this diagnosis, is a study of the seasonal change of the results.
While it is very early, the export of some results from the measurements to date show an indication of a quasi curving behaviour for the south Wall. Quite otherwise, for the north Wall the practically parallel change of the deformations suggests deformation within the level of the Wall.
From the study of the results of the measurements that will be taken over a considerable length of time, and considering other parameters as well, such as temperature changes, strong rainfall etc., the various probable models of the Wall's behaviour will be examined. That is, if its behaviour fits into a classic model of a supporting wall, shell, gravity wall etc. This study, moreover, can also yield conclusions about problems of a local nature, such as the relative humping that is evident locally in the east Wall.

Conclusions - Proposals for future research and monitoring

In the course of the various works of this pilot programme, sensors were installed, an advisor was consulted about the choice of positions for taking the measurements, the first results were interpreted for future structural monitoring and services of a structural nature were carried out on various parts of the Acropolis Wall. The measurements taken placed the structural monitoring of sections of the Wall on the right track.
It is now possible from the evaluation of the deformations and the diagrams to observe the even, diachronical increase, without monotony, of the deformations. The opposite shows a dangerous increase of eccentricity.
From the database and the diagrams danger boundaries can be established.
Characteristics of the building material became known from in situ inspection of the Wall.
Serious density of the cracks exist where they are not visible from the base of the Wall. The building material, moreover, is not especially strong, most likely the opposite.
Apart from structural monitoring, it is evident from research in situ of the features of the north Wall that some intervention is necessary in order to lessen the geo-impulses from the interior toward the exterior. Structural monitoring in this case will be enlightening.
Proposed is the use of an inclinometer in the context of monitoring the deformations in the various parts of the Wall. It will be indispensible to combine the measurements of the inclinometer with those of the deformations.
Finally it is deemed necessary, with the Finite Element method, to make a study of sections of the Wall so as to evaluate the static and antiseismic efficiency, and detailed research of the parameters of behaviour combined with the optical sensors. To monitor the Wall correctly, it is considered necessary to make a combined study of the deformations and shifts, using optical fibre sensors and non-linear analysis of finite data.

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Fig. 6. Position of the sensors at the southeast corner of the Wall

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The highly accurate topographical monitoring of predetermined points on the south and east Wall of the Acropolis

The topographical monitoring of predetermined points on the south and east Wall of the Acropolis was applied experimentally in order to check for any micro-displacements over a period of time. The advantage of this topographical method is that it can monitor a large surface area. From the outset, this technique was intended to be used in conjunction with other highly accurate methods, which we have already seen in this issue.

The main goal was to achieve the greatest degree of accuracy possible. Since the monitoring of micro-displacements is extremely demanding, we tried to make use of the possibilities offered by contemporary topography. The members of the circuit Walls Committee –which consisted of YSMA engineers and Mr. Thodoros Hatzitheodorou, topographer engineer of the Ministry of Culture and Tourism– decided in 2005 that the measurements should be made from fixed topographical points on the Wall, with an orientation which faces toward constant reference bases.

Crucial during the first phase of planning the programme were the choice of areas to be monitored and the positions of the constant reference bases, taking into consideration the serious topographical limitations.

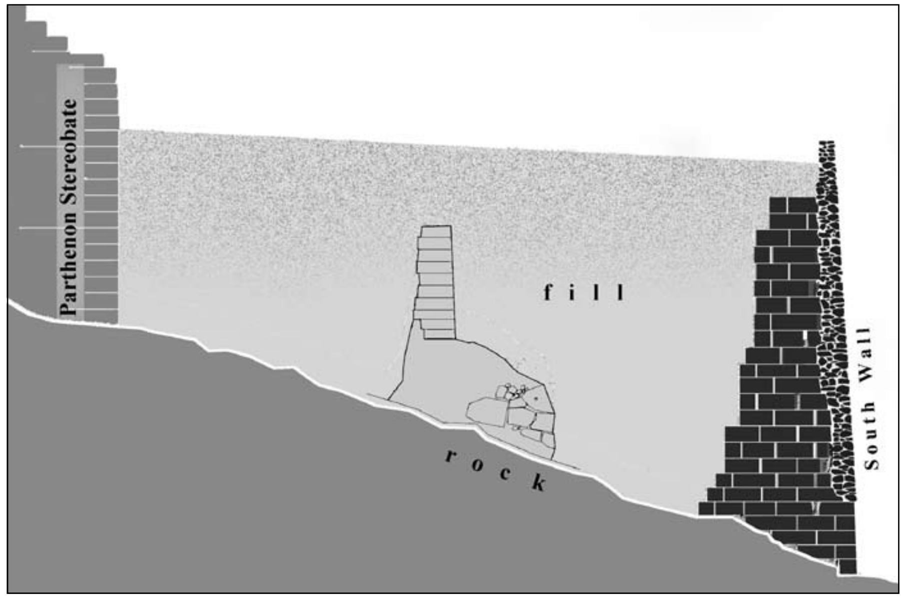

Fig. 1. Schematic section of the south Wall. Drawing V. Manidaki

Fig. 2. Central area of the south Wall, significant detachment of parts of the later sheathing of mixed masonry. Photo Archive -1938

The areas of the Wall to be monitored

During the first phase, the areas of the Wall to be monitored were chosen on the basis of those considered the most critical in terms of their structural stability. The choice was made after a general evaluation of the deformation tendencies, which is based on our current knowledge about the structure of the Wall and on the methods and positions of the repairs made to it during its long history.

The structure of the Wall

The structure of the Wall is familiar to us to a considerable extent from the great excavation of the Acropolis at the end of the 19th century. It is built for its full extent with large rectangular blocks of poros stone, either quarried or in second use, laid in horizontal layers in the isodomic system; its thickness varies from 2 to 6m, depending on its height. In some places the height of the Wall exceeds 18m. In its authentic monumental form the outer surface inclined inward and had stepped recesses ~2-3cm.

For the casual observer today it is difficult to discern the authentic construction of the outer surface, since much is concealed by layers of repairs. In a number of areas a mixed masonry forming a sheath was added in front of the ancient structure. Thus the original clear geometry of the Wall has changed (fig. 1). In particular the inward slope of the surface, appears to be more exaggerated than it was originally. Despite all the outer alteration, the core of the Wall remains unchanged and its outline in general is no different from its ancient form. In the area of the SE corner in particular, the Wall preserves a large part of its ancient surface. It has been filled in only locally with small stones and mortar between the original courses, and not to any great depth.

Deformation tendencies of the Wall

The form of the repairs through the ages is indicative of the structural problems and the tendencies for deformation. The main cause of deformation is due to extrusion because of the severe load of the fill that the Wall retains, a problem that was resolved in the past –in mediaeval times– by adding buttresses.

In some areas structural faults express the aging of the building materials and the gradual reduction of their mechanical resistance. The results are humping and slipping of sections. In the repaired parts, moreover, the loss of resistance in the mortar and the alteration of the binding material resulted in cracks, and caused parts of the interior to separate and, in the past, stones to fall.

By comparing photographs taken over the past 150 years it has been possible to make a macroscopic evaluation of most of the afflicted areas of the Wall.

The greatest separations were observed at the beginning of the 20th century primarily in the central area south of the Parthenon. In this area the Wall is preserved to its greatest height, while its surface is totally sheathed with a later mixed masonry (fig. 2).

The same observation applies to the SE corner, the area where the first repairs were made to the Wall in more recent times (around 1870, shortly after the removal of the mediaeval ramparts). Finally, it is the highest area for the entire length of the structure, and it is also the area that has the greatest number of cracks. The lower zone near the base shows the greatest stability. There the original construction is still preserved throughout its outer surface.

Positions of the points

As outlined above, the network of monitoring points was developed on the south Wall in the areas mentioned and on a small section of the east Wall in order to monitor

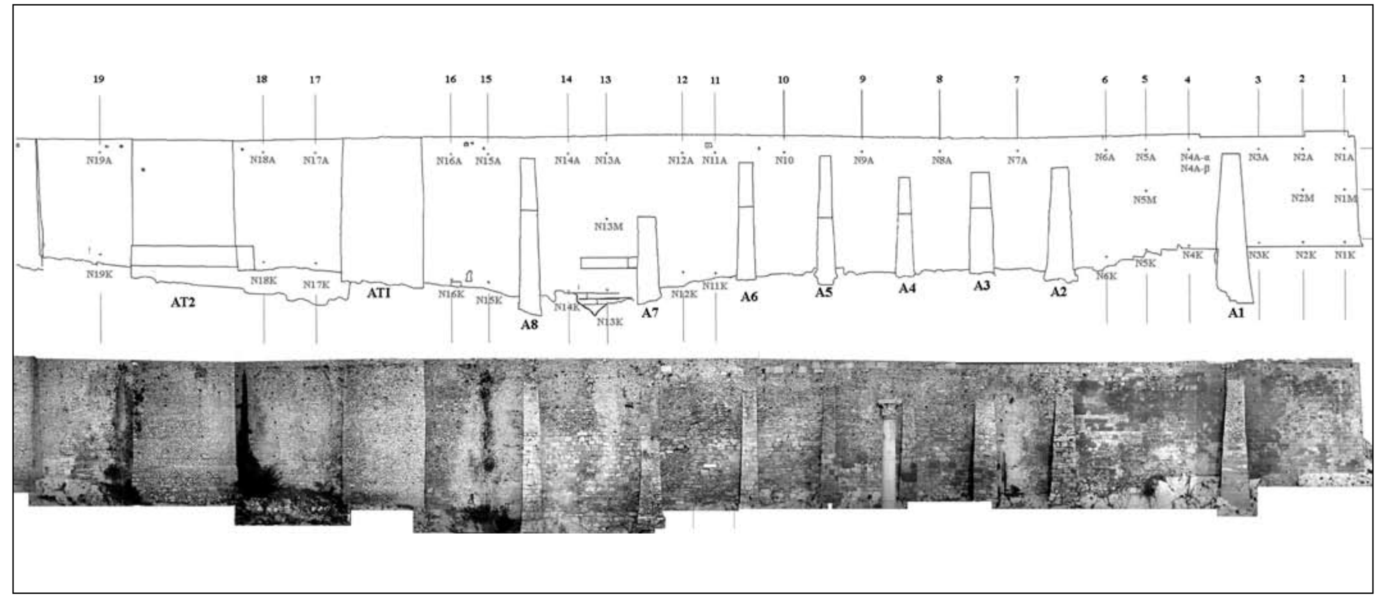

Fig. 3. Setting in three zones by height of 39 topographical prisms on the south Wall. Drawing V. Manidaki

Fig. 4. The area being monitored on the Wall is extended to the east leg of the south Wall (around 155m from the SE corner of the Wall) and to a 12m section of the east Wall

Fig. 5. Base B1: the bright spots indicate the position of the topographical prisms on the Wall oriented toward the base, and are the reflections from camera flash. Photo S. Leloudas

the SE corner. Currently it includes 46 special topographical monitoring prisms, 39 on the south Wall and 7 on a limited part of the east Wall. They have been arranged in three zones of elevation (fig. 3).
The prisms were anchored on the Wall and oriented facing toward the corresponding one of the two predetermined constant reference bases of the topographical instrument. Hard and durable stones were chosen –other than marble– which had shown good coherence with the surface of the Wall.
The installation of the prisms using suspended platforms would not have been possible without the assistance of the personnel of the YSMA electromechanical team, and especially Mr. S. Gousis and Mr. S. Nikolopoulos, who coped with the peculiarities of the work with inventiveness.

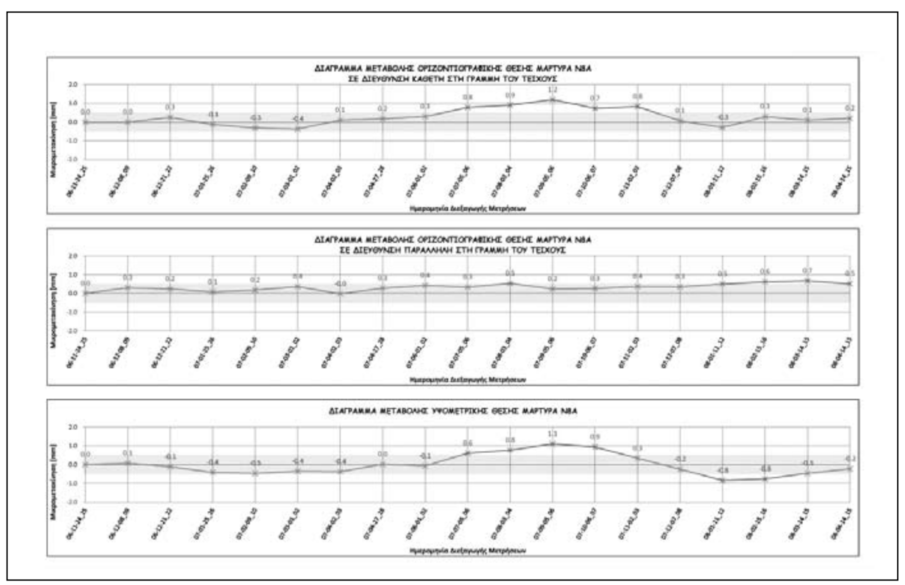

Fig. 6. Indicative diagram of diachronical monitoring of a target on which is marked the deviation from the original position by X, Y, Z. Processing of measurements: S. Leloudas and I. Partsinevelos

The monitoring bases

For choosing the positions of the constant reference bases, the most serious criterion was the topography of the area.
The decisive factors in choosing the position are clear visibility towards topographical monitoring prisms, firm ground and the greatest permissible distance for obtaining the desired precision (~130m). In the present situation, however, sites on the Acropolis rock that have perfectly stable ground, are very close to the Wall. Unfortunately most of the sites with clear visibility towards topographical monitoring prisms within the archaeological zone of the south slope are on fill, on ground that is less firm. The foundations of the monitoring bases, moreover, could not have much extent or depth as they are in the archaeological zone of the south slope and very close to the theatre of Dionysos.
Finally, taking into consideration all the above, the locations that were chosen were, first, on top of the fill and very close to the supporting wall of the Peripatos. The second was on the stone parapet of the enclosure of the archaeological site on Thrasyllos street (fig. 4).

Topographical works

The area of the Wall to be monitored was expanded to a section of the south Wall approximately 155m from the SE corner of the Wall and a section of the east Wall 12m from the same corner. The measurements were taken regularly every month from November 2006 to June 2008. A total of 20 series of measurements was taken.
The topographical monitoring prisms were placed on the above two sections of the Wall and, for taking the measurements, the two constant reference bases that had been constructed in the positions mentioned previously were used.
The topographical instrument used belongs to the High End technology Industrial Geodetic station - Laser Tracker and it can attain a precision of 0.2mm at a distance of 130m and 1cc at corners. The specific instrument has Automatic Target Recognition capability, i.e. it automatically recognises the targets-prisms after the first time, then with each subsequent measurement it centres on the point of intersection of the filaments (fibres) of the prisms. In this way we can verify that the measurements are repeated always at the same points with high precision, actually eliminating the observer's error (fig. 5). During the process of measurement, the factors of temperature and atmospheric pressure are included in the data.
After processing the measurements, comparative diagrams are composed for each target showing the diachronical deviation of the results from the initial measurement in the 3 aiming directions. These directions are perpendicular to the Wall (X), parallel to it (Y) and vertical to the Wall (Z). A total of 20 series of measurements was taken over a period of 19 months. The grey zone on the diagram is the area beyond which we have evidence of displacement (fig. 6).

In addition to the two constant reference bases described in the paragraph "The monitoring bases", three fixed reference monitoring prisms were anchored for each base, in a firm ground near the Wall and on the Acropolis rock in order to give the X, Y, Z coordinates for each base where the Industrial Geodetic Station was set up, prior to each set of measurements.
The field works were carried out at night until dawn in order to have relatively stable atmospheric conditions, so as to avoid diffractions, contractions/expansions (diastole/systole) etc. Nights were chosen, moreover, when it was not windy or raining.
Among the problems of minor significance during the period of regular measurements that added, however, to the difficulty of the work was the occasional lack of visibility, such as caused by the growth of weeds, in some cases hiding a number of the targets. Thus any future extension of the monitoring should be connected with conservation

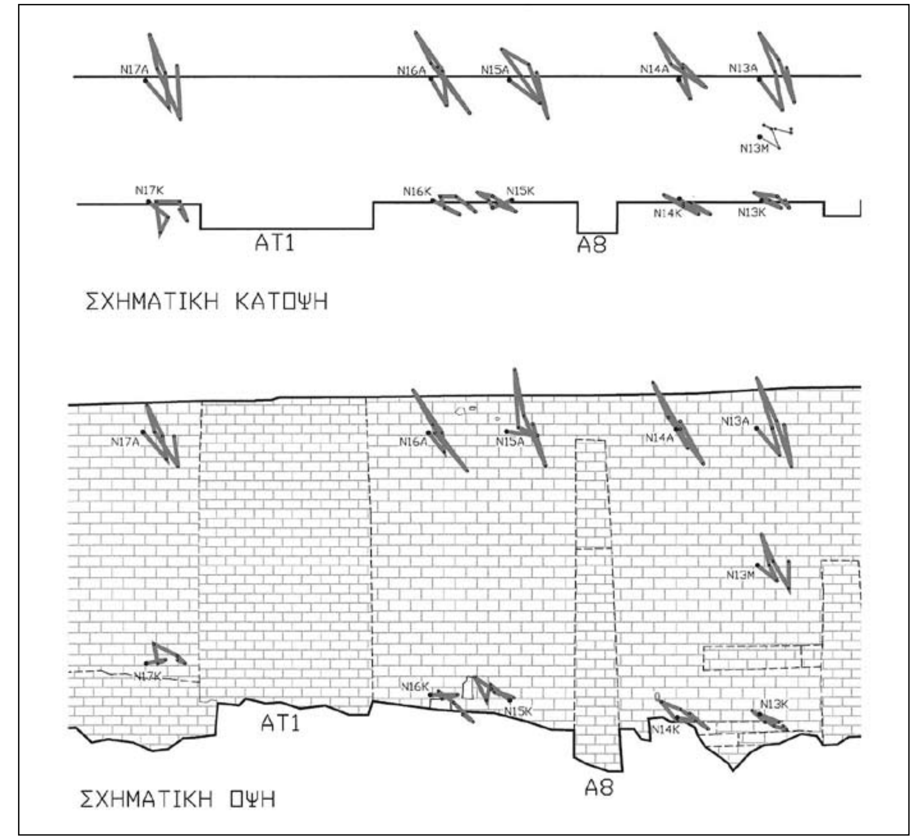

Fig. 7. Vectors of micro-displacement of the central part of the south Wall. Drawing T. Iliopoulos

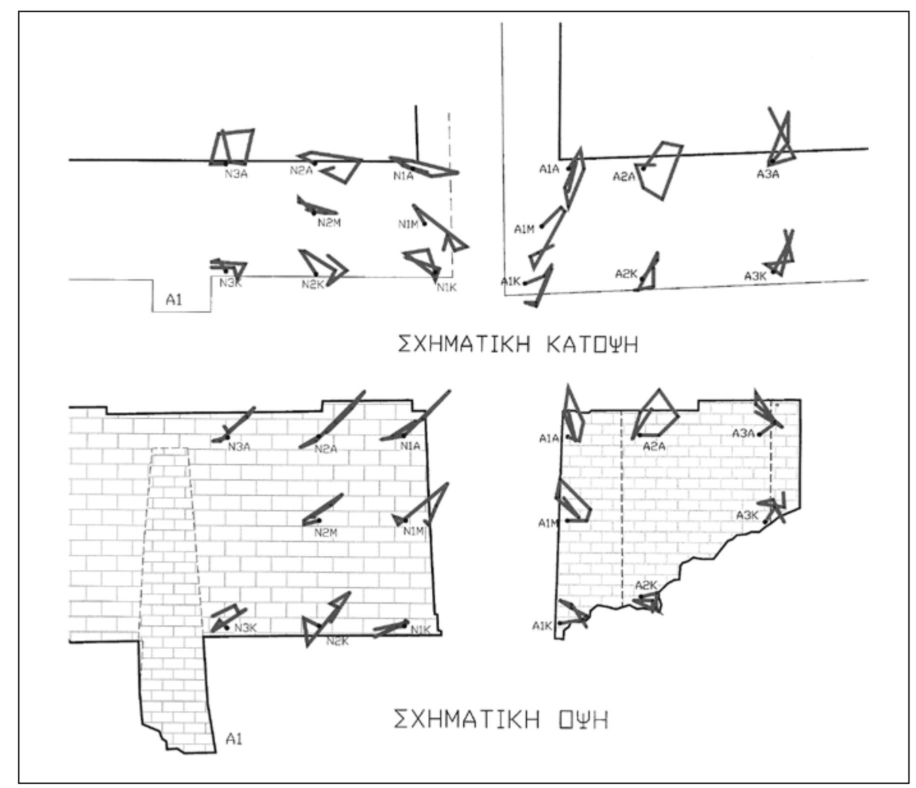

Fig. 8. Vectors of micro-displacements of the SE corner of the Wall. Drawing T. Iliopoulos

of the network and regular clearing of flora that spring up around the targets.

Conclusions

An important element in evaluation of the results is that the indications of minor displacements were observed at the areas near the edges of the Wall, where greater movement would indeed be expected. According to the results of the topographical monitoring carried out to now, measurements at the base of the Wall do not show deviations - they have a spread of less than 1mm, whereas they show an appreciable spread of around 2mm in the upper part in both the Perpendicular and Vertical to the Wall. These are indications of minor displacements according to height and simultaneously an inward movement (intrusion) of the upper part of the Wall, as it appears also on its representation in the vector diagram (fig. 7). The phenomenon is transient and the measurements return to their initial value at a later time.
The indications on the targets either side of the SE corner (positions N1 and A1) are in agreement. They show the same movement (despite the vertical crack being very close to the bend of the Wall) and same diagrams of deviation, in the three directions for the corresponding time periods. Examination of the measurements of the SE corner reveals that the Wall has a tendency toward minor displacements eastward (fig. 8).

Periodicity in time

Although only 19 months have passed, the results of the measurements to date have revealed periodicity of micro displacements over time. A wavy curve in the diagrams of most of the targets is evident, mainly in the upper parts of the Wall, with extreme values in the months of February and September (fig. 9).

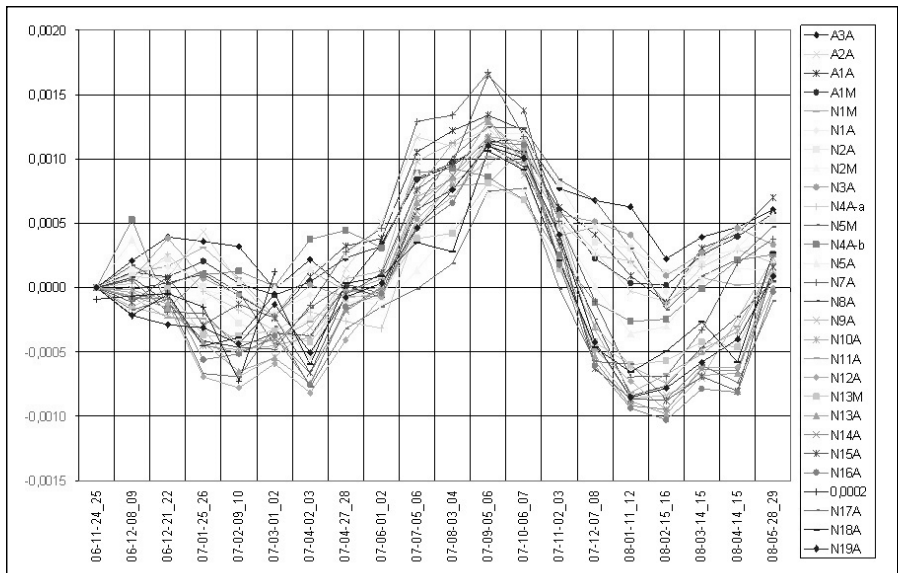

Fig. 9. Diagram of measurements by Z estimate of the targets being monitored. Processing of measurements by V. Manidaki

The gradual increase in height and intrusion of the upper part of the Wall of around 2mm was noted at the end of the summer season. Whether or not the apparent diastole is connected with the corresponding intrusion, which was observed during this same time, is a matter for additional research. To an extent it is certainly related to the small lean of the wall inwards as it was built.
The opposite, a reduction in the height of the Wall and a movement of the upper part of it outwards is observed during the winter months, the greatest values being in the month of February.
These first ascertainments are being formulated with due reservation. We believe that verification of the "wavy curve" of micro displacements inwards-outwards and upwards-downwards of the upper part of the south Wall requires at least double the amount of time for monitoring and recording in order to be certain. Likewise valuable and enlightening is their comparative examination with the detailed measurements given by the arrangement of optical fibres in the area of the SE corner of the Wall. The optical fibres method of monitoring, which was applied during the directly succeeding time phase and is under development, appears up to now to support this conclusion (see the report of D. Egglezos in the present fascicle).

Proposals

Continuation of topographical monitoring may confirm with greater assurance today's evidence for micro-displacements in a periodic time-frame.
The stable targets of the rock can be limited to 2-3 in common for the 2 bases, with the use of suitable prisms, so as to limit the uncertainties and mitigate the differences in measurement of the stable targets of the rock.
A full series of measurements is proposed following exceptional events such as earthquakes, heavy frost or heat-waves.
The monitor network can be made denser or it can be expanded with the addition of new prisms in areas that need to be monitored in the future.

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Rural and Surveying Engineer
Spyros Leloudas
Mechanical Engineer

Vasileia Manidaki, YSMA architect, was in charge of the work. The topographical study was entrusted to Thodoros Iliopoulos, Ioannis Partsinevelos, rural and survey engineers, and Spyros Leloudas, mechanical engineer, after bidding under public tender, issued by YSMA in 2006.

The Acropolis circuit Walls are a characteristic example of a monument that allows, or better, requires the use of modern technological systems (MTS). This is evident in the systematic peculiarities of the circuit Walls, in comparison with the other monuments of the Sacred Rock. These include:
• The great length of the monument.
• The differences in building technique found in different areas.
• The sharp relief of the rock on which it is founded, which makes it especially difficult and in places impossible to approach for direct visual inspection.
• The weighty history of damage and failures.
• The structural function of the monument as a retaining gravity wall and the complete interaction with geomaterials in contact (foundation rock - supported earth).
• The tremendous actions by high horizontal soil thrust, in both static and seismic circumstances.
It should be noted that the above difficulties and peculiarities together with the restoration priorities of the other monuments on the Acropolis already included in the programme of the ESMA, meant that in the past it was not possible to begin work on restoring the Walls.
This "delay", however, made it possible for the YSMA to enter the restoration of the monument in a completed interdisciplinary plan of studies and interventions [4], which made use of:
• The invaluable experience gained in carrying out the works of restoration on the other monuments of the Acropolis [5].
• The development of strong computational tools and the significant emergence of scientific fields (for example rock mechanics, soil dynamics), the combination of which yields solutions to compound problems of interacting structural systems and geomaterials [3].
• The development of building techniques and practices, which permit successful interventions in complete accord with the principles of restoration.
It is evident that the use of modern technological systems in the process of anastelosis has to be entered in an overall plan rather than functioning as an isolated act with limited ability to produce results.
In this light, the modern technological systems employed in the restoration of the circuit Walls are incorporated in the general design that is described analytically in table 1. It includes six discrete successive phases of restoration that start with the documentation of the monument and the determination of the required (local or total) intervention, and they end with its monitoring and conservation after the restoration is completed.
The modern technological systems applied to date are the following:
• Three-dimensional scanning and photogrammetric recording (PHGR) for geometric documentation of the monument and the underlying rock [10, 9].
• Topographical measurements (TM) of high accuracy for monitoring the micro-displacements and/or deformations.
• Instrumentation with optical fibre (OF) sensors for monitoring the strains caused by mechanical loading and temperature [1].
• Array of accelerographs (AA) for accurate determination of seismic motion and dynamic response of the entire monument.
• Construction of a digital platform for entering all restoration information into a suitable database (DB) that can handle also spatial information (GIS) [10, 9].
Shown next are characteristic examples of actions in which the modern technological applications described above have been employed.

Three-dimensional scanning and photogrammetric plotting

Back analysis for the interpretation of structural damage in the north Wall
The example refers to the interpretation of significant structural failure in an area of the north Wall. The failure occurred, according to the available historical and archaeological evidence, at the end of the 18th or beginning of the 19th century and it includes: a) the collapse of the upper part of the Wall in the area examined (that is to say the crown of the Wall that had been constructed of architectural members of the entablature of the Archaios Naos of Athena), b) significant outward lean from the vertical

CIRCUIT WALLS+ROCK

INTERVENTION STAGES	TASKS	TECHNOLOGY APPLIED
A. DOCUMENTATION SUPPORTING STUDIES DATA COLLECTION	*Archaeological, Geometric, Damage Report, Architectural, Geological/Geotechnical, Seismological-Dynamic Response, Properties of structural materials, Instrumented Recording*	O.F., T.M., PHGR, A.A.
B. MODELING EVALUATION OF EXISTING STATE	*1.Modeling: (geometry+ structure + materials + actions + method of analysis)* ← *calibration of parameters*; *2. Model evaluation: back analysis for the interpretation of pathology +accordance to measurements* (NO → calibration of parameters; YES ↓); *3. Evaluation of existing state: assessment of existing safety*	O.F., T.M., PHGR, A.A.
C. DESIGN OF (alternative) RESTORATION MEASURES (>1 !!!)	*Feasibility Study*	O.F., T.M., PHGR, A.A.
D. MANGERIAL STAGE FINAL STUDY according to anastelosis principles	*INSTITUTIONAL DECISIONS - FINAL STUDY (general & detailed) 1. Selection of anastelosis method 2. Conduction of final studies+tendering procedures 3. Final approval - Contract assignment etc*	O.F., T.M., PHGR, A.A.
E. IMPLEMENTATION OF ANASTELOSIS MEASURES	*Supervision- quality control- instrumented recording for safe implementation*	O.F., T.M., PHGR, A.A.
F. CONSTANT OBSERVATION	*Evaluation of measures performance- constant preservation*	O.F., T.M., PHGR, A.A.

DOCUMENTATION- D.B. + G.I.S.
SAFETY - ALARM LEVELS: O.F., T.M.

Table 1. Summary of implementation of modern technological applications in the anastelosis of the circuit Walls and the Acropolis rock

Fig. 1. Area of the analysis. Interior view of the north Wall. Photo D. Egglezos, 2008

(7cm) of the remaining lower part (that is, the part beneath the crown that collapsed), c) rotation of approximately 1° (fig. 1).

The purpose of the analysis (which is a preliminary approach for the design of restoration measures for the circuit Wall of the Acropolis, with emphasis on anti-seismic planning), is to evaluate the modeling of the case problem and the calibration of the mechanical properties used for interpreting the structural failure. For the relevant calculations, the principles of rock mechanics were applied for simulation of the dry-masonry construction [3].

For correct description of the problem, information is drawn from a wide range of scientific specialisation: historical-archaeological, architectural, seismological and geotechnical-geological. Particularly important is the use of a precise geometrical model, acquired from three-dimensional scanning of the area [6].

As a result of the analysis significant horizontal movement in the crown (of the original) cross-section was observed, which, together with the geometry of the blocks of the crown (cornice form Γ) and their overloading by new wall construction, may have caused them to fall. Especially so, if we take into account chance pre-existing displacement – rotation from previous seismic action. Just below the cornice (in the position corresponding to the analysed crown of the actual section with structural failure), the calculated horizontal displacement was 8cm. This value agrees well with the observed displacement of 7cm. It may be noted that this value is not a result of "processing" the data, but is an objective product of the original analysis. Moreover, from the strength index (tension-compression ratio), the image of cracks in the exterior view of the section examined emerges clearly (fig. 2a-b, see also fig. 1).

From the result it is apparent that the simulation has succeeded and that it can be used for the analysis of consolidation in areas of the Wall with prevailing plain strain conditions, that is, far from corners and areas with strong geometric discontinuity [2].

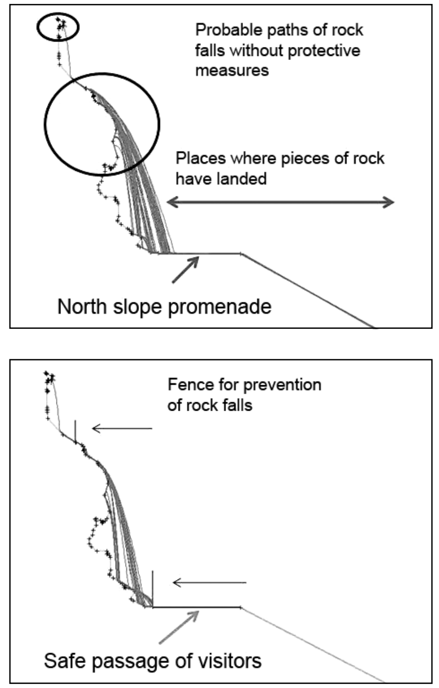

Fig. 3a-b. Rockfall paths in an area of the north Wall a: without protective measures, b: with protective measures. Diagram D. Egglezos

Monitoring rock falls from the north Wall

The precise geometry of the Wall and the underlying rock, as shown by the data of the three-dimensional scanning, is a basic

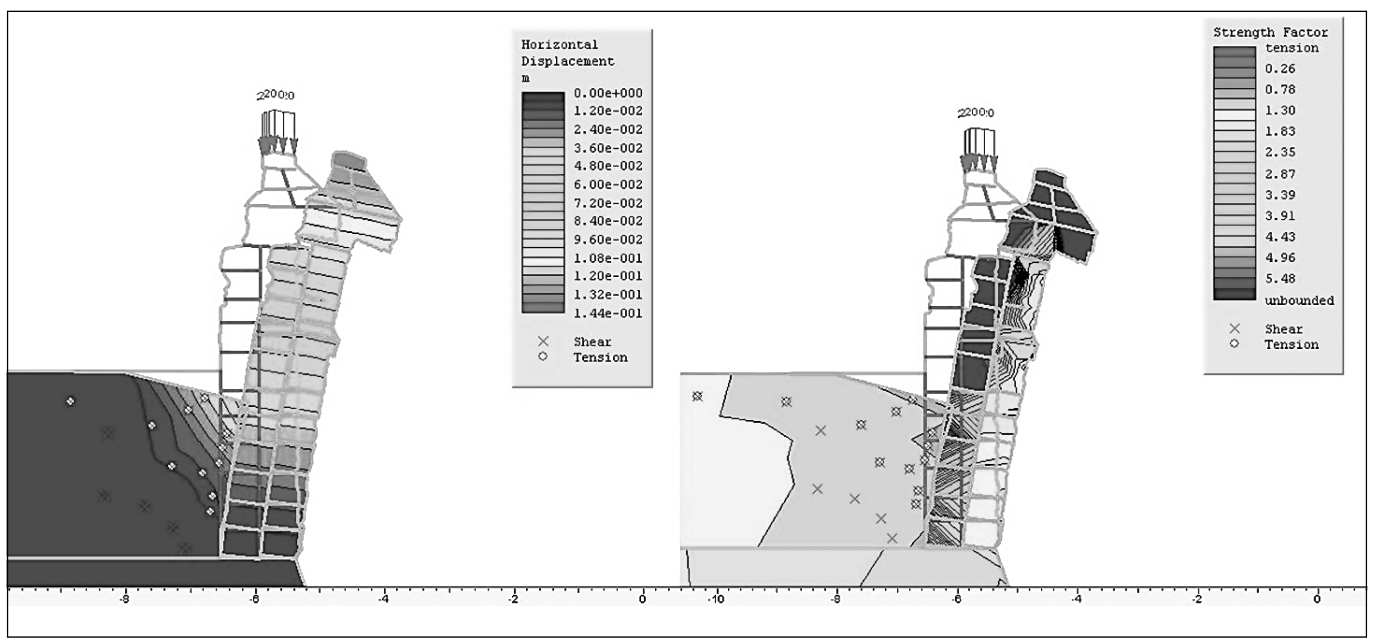

Fig. 2a-b. Results of the analysis a: Horizontal displacement, b: Strength gauge. Diagram D. Egglezos

requirement for designing protective measures for trapping the rock falls. In fact the analyses of rock falls show great sensitivity to small changes of geometry and can affect significantly the final result (site of the works, cost, aesthetic result).

The need for designing these measures is imperative, in the opinion of the writer, and the following features are therefore cited:

1. "The condition of the rock as seen on the surface is generally fractured (greatly so in places). This fracturing is stronger on the north side of the rock" [7].
2. Strong surface fracturing was verified during the process of weeding the slopes (December 2007 - January 2008), from which the present writer took care to remove the possibly dangerous fragments of the rock that were revealed after clearing out the weeds.
3. Instability and falls of massive pieces of rock from the Acropolis slopes have been recorded in many cases, even recently. Worth noting is the massive piece of rock (size about $1m^3$) that broke loose in March 2006 after a heavy rain.
4. Constant falls of small rock blocks were also observed during informal collaboration of the author with the 1st Ephorate of Prehistoric and Classical Antiquities in the framework of monitoring the Klepsydra (Spring 2008).
5. In the past, studies had been made and measures taken to consolidate various areas of the hill. Specifically, the masonry added to strengthen the wall around the middle of the north side by Balanos (after continuous falls of very large rock fragments) [8] and systematic anchoring in places in the context of the work of anastelosis beginning in 1976.

It should be noted that the uppermost part of the masonry shows consistent cracking, which clearly indicates movement of the supported rock.

On the basis of these facts, preliminary analyses were made in order to evaluate the danger to the north section of the Peripatos, so as to design suitable measures for protecting walkers. Included in the broad interpretation of rockfalls are possible falls of sections or structural members of the Wall (see the previous example of back analysis).

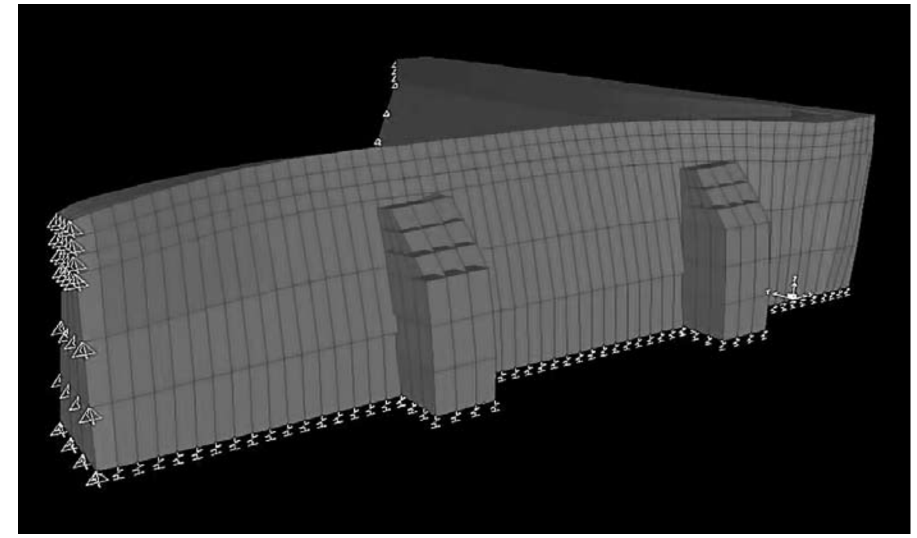

Fig. 4. Results of three-dimensional analysis with temperature load: strain field. Model (3D) D. Egglezos

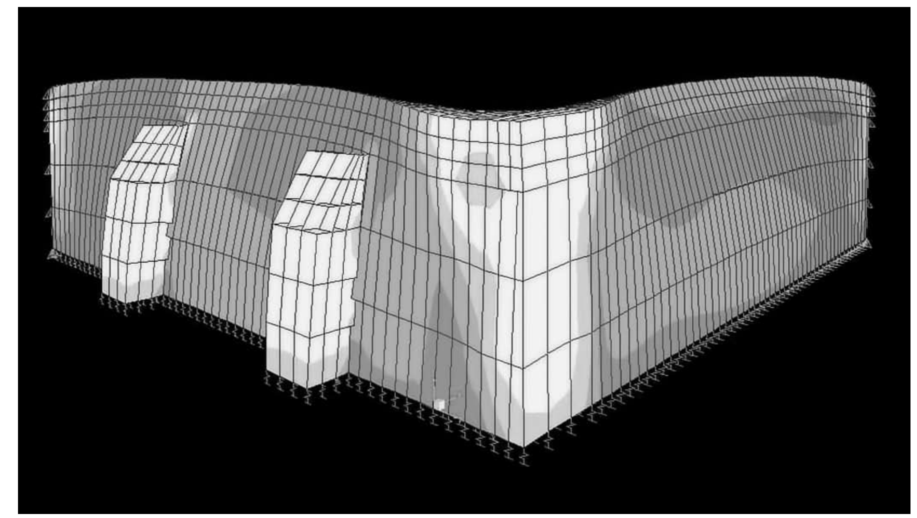

Fig. 5. Results of three-dimensional analysis with temperature load: stress field. Model (3D) D. Egglezos

Used for the analysis was the section of the previous case on the basis of the following criteria:

- History of failure.
- Unfavourable geometric characteristics of the rocky slope.
- Significant numbers of technicians and visitors that gather in the area to use the lift.

The analyses (fig. 3a) show a clear danger for those approaching, given that the falling blocks clearly threaten the north part of the Peripatos and can even reach the north boundary of the archaeological site (entrance opposite the Kanellopoulos Museum). Repetition of the analyses with the placing of buffer barriers in appropriate locations assures a safe approach (fig. 3b).

Topographical measurements of high accuracy

Topographical measurements of high accuracy are used for measuring micro-displacements of the Wall (monitoring safety). From the results available to now, it is evident that the displacements:

- Are periodic within the yearly cycle.
- Are within secure limits: ±1.5mm.
- Are due mainly to stress from variation

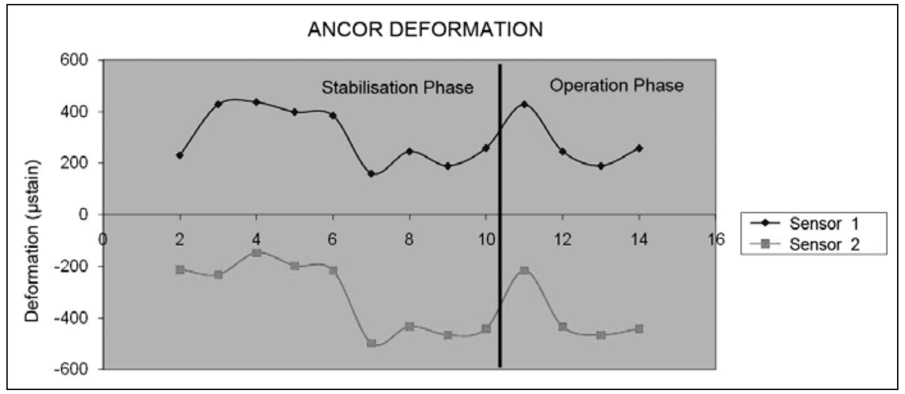

Fig. 6. Measurements of deformation of anchor with optical fibre sensors

Comparison of movements:		
Calculations	Measurements T.M.	Quality observed
δV=0.6-1.4mm	δV=0.5-1.5mm	lifting
δL=-0.2-0.1mm	δL=-0.5-0.0mm	lengthwise movement (E → W)
δS=0.3-2.5mm	δS=0.5-1.5mm	outwards movement (S→N)
ERROR T.M.: ±0.5mm		

Table 2. Comparison of movements from analytical calculations with topographical measurements

of temperature and microchanges in earth thrust.

In the present example, topographical measurements are used also for validating the three-dimensional model of the SE area of the Wall: specifically, the strain field in the south area of the Wall, arising from the action of the temperature load that corresponds to summer heat.

The model, simplified on purpose, contains the following:

- Elastic analysis (choice supported by taking measurements periodically).
- Idealised geometry of the Wall.
- Documentation of the Wall as a continuum with reliable properties of the masonry body [2].
- Sufficient length so as to limit, to the extent possible, the effect of the bordering restraints.
- Temperature load (because of change in the environmental temperature) of around 20°C, given that the reference measurement was taken in the month of November.

The strain resulting from the analysis (fig. 4) is in clear agreement, from the standpoint of both quality (lifting, transverse movement, longitudinal movement from E to W) and quantitative level (table 2) with the data derived from the topographical measurements of the same section of the Wall. Thus the model used for preliminary analyses is sufficient.

Instrumentation with optical fibre sensors

The use of optical fibres is evident in the following examples where:

A. The model referred to previously is validated anew.

B. The performance of stabilising anchors (used for stabilisation of the rock mass), is evaluated.

Case A

In the context of validating the model, examined also as an indication were the results from the optical fibre sensors that had been placed on the upper part of the south Wall, in E-W direction. Both the measurements and the calculations (table 2) indicated a shortening of the Wall in an upward direction. Moreover, in the area of the sensor observed, on the basis of the calculations of compression, likewise in the direction E-W: -25 kPa $>\sigma_{11}>$ -40 kPa, which compares well with the results from the measurements: -35 kPa $>\sigma_{11}>$ -50 kPa (fig. 5).

The above evidence reinforces the sense that the model of the SE area of the Wall (concerning the stresses to which it has been subjected, and the properties of the materials), is good and can be used as a base for more complex analyses.

Case B

In the context of the work "Consolidation of small rock blocks at the SE corner of the Acropolis rock" an anchor was chosen on which were placed two optical fibre sensors. The sensors were set in the middle of the anchor and at antidiametrical positions, so that in addition to the axial deformations it would be possible to record shear phenomena in cases of massive rock slide.

From the results of the measurements (fig. 6) it was evident that the anchor shows systematic shortening (440μm), which is due to uniform temperature change. The situation was evaluated analytically on the basis of reasonable assumptions about the temperature change (20°C) and the thermal properties of the steel. The calculations show a shortening equivalent to 460μm, which agrees well with the measurements.

The most significant result, to be sure, is that the rock mass remains stable and the anchor does not stretch.

Array of accelerographs

Full utilisation of the accelerograph array is

not possible at present since the calibration of analyses of strong response presupposes severe seismic motion, which will be recorded by all the instruments of the array.

Database and Geographical Information Systems (GIS)

The intention is to supply the database with all existing information about the Wall and to create through the GIS multilevel thematic maps for their more complete utilisation. Pilot data have already been entered from the repair of part of the interior side of the east Wall (fig. 7). Information is to be added continuously to the database during the course of the work.

Conclusions

From analysis of the above we may easily conclude the following about modern technological applications:

1. They form an inseparable part of the contemporary process of restoration.
2. They provide a non-destructive acquisition of data about the properties of the materials and their structural behaviour, a fact that is especially significant in the case of the monuments (undesirable minor damage for material sampling is minimalised).
3. They contribute the most to continuous monitoring and control of the safety of a monument.
4. They permit continuous control of the digital calculational tools and the methodology of producing a model of the monument, in the context of interaction of measurements/data from contemporary technological applications and the results of the analyses.
5. Their correct use requires their incorporation in a processed plan of anastelosis. In each case, indeed, the correct application of modern technological programmes to the demanding and complex problems posed by the restoration of monuments, emphasises, as a basic lever of success, the human element, in this case the judgement and experience of the engineer.

Finally, it should be emphasised that the successful use of modern technological applications provides an excellent example of interdisciplinary collaboration as a critical component of successful anastelosis.

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Walls programme YSMA

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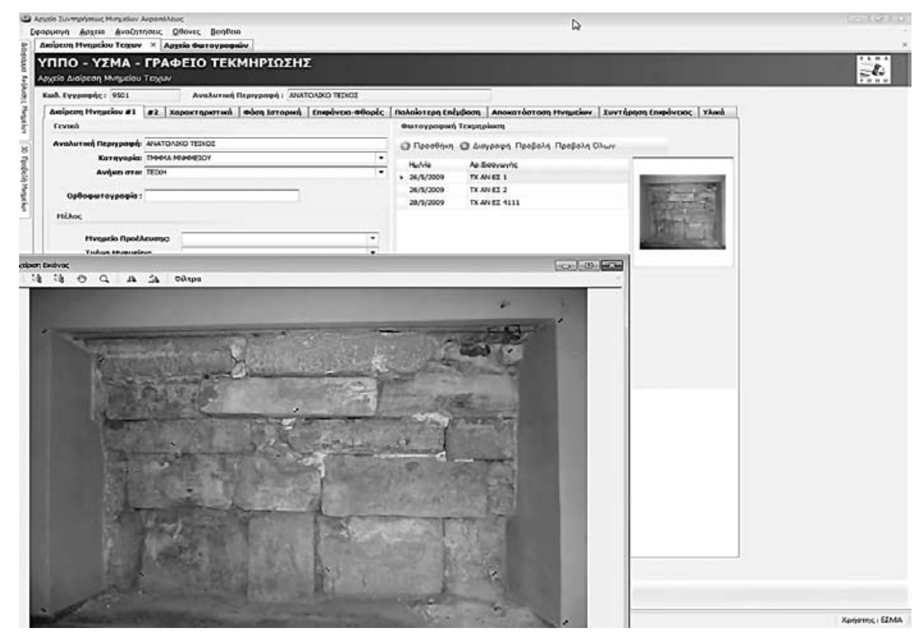


Fig. 7. Database card: record of repair to interior area of the east Wall

The north side of the Parthenon showing the resetting of the last architrave block. Photo V. Eleftheriou, 2009

General view of the Acropolis from the W. Photo S. Gesaphidis, 2009

This year will see the completion of the great restoration programme of the Acropolis that began nine years ago when a newly organised service, the Acropolis Restoration Service (YSMA) was called upon to carry out a very extensive work. Although it was newly established, the Service had at its disposal scholarly knowledge and experience, since it had incorporated all the scholarly and technical personnel who had worked during the preceding years on the Acropolis. Most important, however, it had the scholarly supervision and support of the Committee for Conservation of the Acropolis Monuments (ESMA), the interdisciplinary committee that from 1975 was responsible for the interventions on the Acropolis monuments. To the ESMA is due the development of the principles and methodology for restoring classical monuments, a field in which our country had already won international recognition.

The programme we were asked to carry out in 2000 was titanic. Interventions, simultaneously, on the Parthenon, the Propylaia and the temple of Athena Nike, work on the circuit Wall of the Acropolis, conservation of the surfaces of the monuments, recording and study of the architectural members scattered over the rock, and so on.

I remember with emotion the anxiety that seized all of us the evening of February 13, 2001, while we were waiting outside the meeting hall of the Central Archaeological Council (KAS) to present our programme and the preparation of YSMA for approval of the beginning of the greatest restoration programme that had ever been carried out on the Acropolis. We had made satisfactory preparations:

• approved studies existed for all the works proposed,
• we had researched the installation of a new crane for carrying out the work of restoring the north side of the Parthenon,
• the study for the bridge cranes to be used in the Propylaia was ready,
• we had assured the supply of marble needed from the Dionysos-Penteli quarries,
• thanks to the powers accorded to the YSMA in the Presidential Decree that established it, we had acquired the necessary additional scholarly and technical personnel to carry out the works, based strictly according to merit,
• we had researched and studied arrangements and special constructions that would accelerate the works and
• we had generous funding from the 3rd Community Support Framework that was a presupposition for the development and acceleration of the Acropolis works.

The unanimous approval of the extensive programme by the KAS, together with the positive comments about the Service's level of preparation, made us very happy indeed, but it did not lessen our anxiety. We knew that we had before us an intensive work and great difficulties. We knew well that, despite the studies we had for all the interventions on which we would embark, we would confront damage and problems as yet unknown to us and that we would discover them after dismantling the monuments. Problems that demanded other supplementary studies or the extension of the interventions over larger areas of the monuments. And all this, with the continuous threat of time and the effort to respond every so often to the reasonable question of the populace: "But when will the Acropolis works ever finish?"

In the end the work accomplished on the Acropolis was far greater than that originally approved. A total of **1,094 architectural members weighing 2,675 tons** were restored to the monuments. The Greek State and the European Union responded to the requests of the YSMA and the ESMA for approval of other programmes and for an increase of funding from national and community sources.

Today, with the work coming to its conclusion, I shall present the works of the past year through photographs of the monuments that have already been freed from the scaffolding or are in the gradual process at this time.

On the **Parthenon**, the restoration of the north side of the monument, which was the most extensive programme to have been carried out on the Acropolis, was completed a few days ago. The works on the north side were supervised by the architects N. Toganides –who is also the head of the restoration of the Parthenon– V. Eleftheriou and L. Lambrinou. The studies for the structural restoration were made by the civil engineers A. Vrouva and G. Stephanou. In charge of the documentation of the work of restoration of the Parthenon is the archaeologist E. Karakitsou. Contributing also to the work was the architect A. Papandropoulos. The marble technicians were led by G. Angelopoulos and D. Phoskolos.

The work of restoring the north side of the Parthenon called for the dismantling of eight middle columns (from the 4th to the 11th from the east) and the corresponding areas of the overlying entablature so as to remove the cement and rusted iron of the previous restoration and to reset the incorrectly placed architectural members. The intervention was extended to the west section of the north side, following the study by R. Christodoulopoulou, in order to transfer six of the original metopes to the Acropolis Museum and to replace them on the monument with cast copies.

Completed in the course of the past year is the structural restoration of the remaining members of the entablature (diazoma, frieze and cornice blocks), setting in place all the ancient fragments that were identified. The members were replaced on the monument, in their original positions. Also set on the monument were the copies of the authentic frieze blocks that had been removed. In addition, the final surface of many of the architectural members was tooled and the carving of the flutes in the fillings of new marble was completed on the 9th, 10th and 11th columns of the north colonnade.

All the works are accompanied by systematic photographic and graphic documentation. Photographic and topographical surveys were made in order to produce orthophotomosaics of all layers of the entablature. Processing and final production of the orthophotomosaics was by the rural and surveying engineer D. Mavromati.

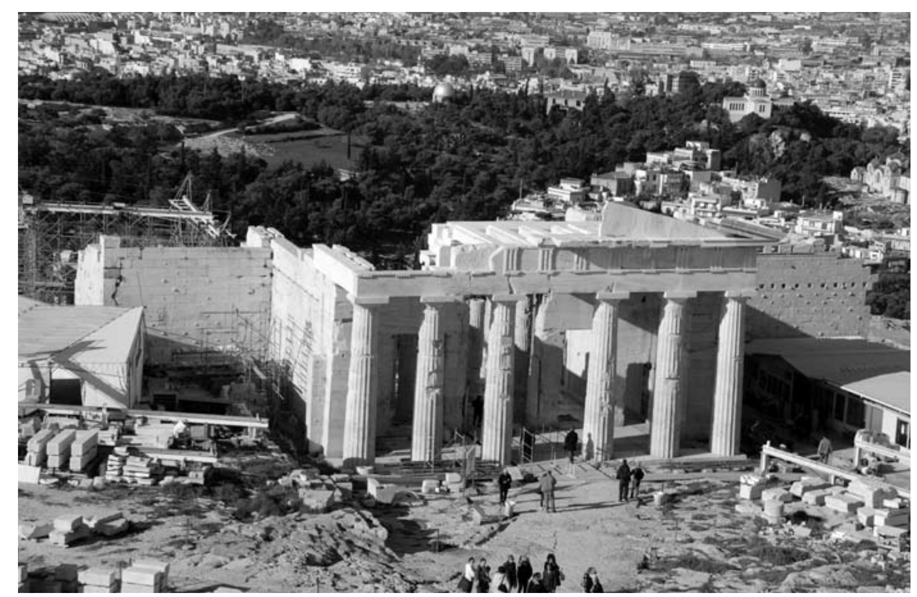
It should also be mentioned that with the opportunity provided by the new exhibition of the Parthenon sculptures in the Acropolis Museum, 29 frieze blocks and 26 metopes of the monument were depicted by the architect A. Papandropoulos and the draftsperson K. Matala.
Currently the scaffolding is being removed from the north side of the monument, so as to give it again to the general public. Completion of the intervention in this area, besides increasing the static efficiency of the monument, has increased its aesthetic quality, since the north side together with the west, form one of the most complete views of the monument, both for the visitor who is entering and for the spectator who sees it from most places in the city.
In the **Propylaia** restoration of the ceiling of the east portico was completed and the scaffolding removed. It should be remembered that the restoration of the ceiling of the west hall of the central building had already been completed in 2008. The head of the Propylaia restoration work is the architect T. Tanoulas. Participating also in the work is the architect K. Karanasos and, until June 2009, the civil engineer V. Papavasileiou. In charge of documentation is the archaeologist E. Petropoulou. The highly experienced draftsperson G. Moutopoulou provided important assistance in the work. Supervising the work team is the greatly experienced marble technician G. Regos.
Completed during the past year in the Propylaia is the restoration of the members of the entablature of the east portico, with the setting of the tympanum and the sima blocks. In addition, the structural restoration of the two last ceiling beams of the east portico was completed with the inclusion of ancient fragments and fillings of new marble. These beams were then reset in place, as were all the coffered slabs. The ceiling of the monument was then sealed with a special proven mortar and finally, in December 2009, the bridge-crane and scaffolding were removed. The programme for restoring the ceilings of the central building, which was applied in the Propylaia, called for the extension of the restoration over an area twice as large as that restored at the beginning of the 20th century. This choice greatly increased the didactic value of the monument, since the visitors now enter beneath a part of the Propylaia that is roofed and have the opportunity for a better understanding of the spatial arrangement and the architectural forms.
At present, work is proceeding on removal of the protective flooring of reinforced concrete that had been made to protect the authentic floor of the Propylaia before the intervention. At the same time, preparatory work continues on the members that will be incorporated in the south wall of the central building, in accordance with the approved study by the architect K. Karanasos. Finally, the architect T. Tanoulas is working on the study for the restoration of the south wing of the Propylaia.


Cutting the flutes in the marble filling of a drum in the north colonnade of the Parthenon. Photo L. Lambrinou, 2009


Resetting a cornice block of the Parthenon by means of a cramp. Photo L. Lambrinou, 2009

The **temple of Athena Nike** has been the focus recently of all the efforts of the Service, with the intention of completing the works by the end of July. This will allow the removal of the bridge-crane and scaffolding next August. Head of the work of restoring the temple of Athena Nike is the civil engineer D. Michalopoulou, with the participation also of the architect K. Mamalougas. Documentation of the work is in the hands of the archaeologist E. Lembidaki. Head of the work team is the very experienced marble technician, L. Zacharopoulos. It is notable that the work on the temple of Athena Nike encountered serious difficulties when, in July 2009, the contracts of nine of the work force expired. To resolve the problem the assistance of personnel from the Parthenon and Propylaia work forces was necessary.
The structural restoration of the architrave blocks of the temple has already been completed. The beams and coffered slabs of the ceiling of the monument have been set in their final places. The matching of the copies of the frieze blocks has been carried out by the Propylaia team and their setting on the monument is under way. The personnel from the Propylaia team have also carved the five lion-head water spouts on the sima blocks in new marble, in which the ancient fragments that have survived were incorporated. Matching of the members of the east (blocks of the horizontal and raking cornices and tympanum) and west pediments (cornice blocks) is proceeding on the ground, so that, as soon as the copies of the frieze blocks are in place, these members can also be set. The final working of the surfaces of the architrave of the monument was carried out by personnel of the Parthenon team. During the next two months the same team will undertake the carving of the unworked part of the wall surface of the temple.
The **recording of the scattered members**, under the supervision of the archaeologist E. Sioumpara, continued with systematic description, documentation and research on the poros architectural members that are scattered on the Acropolis. Most of the members come from the Archaios Naos of Athena Polias and from the archaic Parthenon. Catalogued already are 783 poros architectural members with 106 fragments identified as belonging. In the context of work on the scattered architectural members, 219 poros architectural members were transported to storage in the Belvedere storeroom. This has been restored, with shelving and with suitable mechanical installations from the electrical-mechanical team.
The scattered architectural members' team undertook also research and moving of the stone pile that lay at the west end of the Parthenon, and also the inscriptions that were in that area. This preliminary work was considered necessary as a preparation for the restoration of the west side of the Parthenon.
During the past years important work has been done on the **circuit Walls** of the Acropolis, a monument of great significance with continuous repairs from antiquity onwards that have contributed to its preservation to the present time. Until last summer, when his contract with the Service expired, the geotechnical engineer D. Egglezos was in charge of the work. The purpose was to document analytically and to monitor systematically structural faults, cracks and distortions of the Wall, using the most advanced methods of electronical recording, so as to study its static efficiency, to draw up studies and to carry out interventions of a rescue nature on the Wall.
To document the Walls, the following was done:
• Topographical measurements of high accuracy using a geodetic station, under the direction of V. Manidaki.
• Documentation with advanced photogrammetric methods.
• Installation of a system of optical fibres.


View of the restored ceiling in the east Stoa of the Propylaia. Photo T. Tanoulas, 2009


View of the Propylaia from the NW corner of the Parthenon. Photo T. Tanoulas, 2009

• Installation of a network of accelerographs in cooperation with the Geodynamic Institute of the National Observatory of Athens. The Institute, in collabration with the YSMA, made studies of seismic danger and effect of geological conditions in the area of the Acropolis that can be used in the studies for restoration of the monuments.

Continued and completed during the past year, were the **works of the Section of Surface Conservation** of the monuments, headed by the chemical engineer E. Papakonstantinou, in areas of the monuments undergoing restoration, and some other areas as well. It should be noted here that during the course of the conservation programme of 2001-2009, a total of **1,129 architectural members** underwent surface conservation. Special emphasis, during this past year, was given to conservation and cleaning with the original laser system developed by the Foundation of Research and Technology of the University of Crete (FORTH) in collaboration with the YSMA. The method was chosen and applied for cleaning the ceiling of the Porch of the Caryatids in the Erechtheion. A total of 14 architectural members out of 40 coffered blocks have already been cleaned. Revealed in the course of cleaning, were traces of painted decoration and traces of ancient paint. Apart from the application of non-destructive methods of analysis for the study and analysis of these traces, research on traces of Egyptian blue is being carried out in collaboration with the British Museum.

The work of the **Support Section** is particularly important and it includes:

• The electromechanical team, headed by the mechanical and electrical engineer S. Oikonomopoulos, which specifies, designs, installs, conserves and repairs the mechanical equipment required for the interventions of anastelosis, the electric tools of the works and all the networks of infrastructure on the Acropolis rock.

• The Laboratory for producing moulds.

• The Information and Education Department, headed by the architect-archaeologist C. Hatziaslani and with the members of the department, the archaeologists E. Kaïmara and A. Leonti.

• The Office of Documentation of the interventions, headed by the archaeologist F. Mallouchou-Tufano until 22 September 2009 and E. Lembidaki from 28 March 2010.

View of the temple of Athena Nike from the east showing setting of the ceiling beams. Photo D. Michalopoulou, 2010

Positioning a coffered slab in the ceiling of the temple of Athena Nike. Photo K. Mamalougas, 2010

• The Accounting Office headed by P. Katsimichas.

• The Secretariat, with Ch. Papanikolaou in charge.

• The Photographic Laboratory, with S. Mavrommatis in charge.

During the past years **YSMA projects** that were funded by the **Information Society (IS)** were completed. Their purpose was to make use of digital technologies for documenting and graphic surveying of the monuments, and for promoting the Acropolis monuments and the work of restoration for the scholarly and general public. These projects were completed successfully and were presented analytically in a one-day conference on 19 March 2010 at the Acropolis Museum.

Before concluding the presentation of the work of the YSMA during the past year, I should like to mention the publication of the *Acropolis Restoration News*, of July 2009, produced by F. Mallouchou-Tufano, and the publication entitled "The restoration of the Propylaia of the Athenian Acropolis" by the present author.

With the completion of the great restora-

View of the east section of the temple of Athena Nike from above after setting the architrave and ceiling beams. Photo S. Gesaphidis, 2010

tion programme, which began in 2000, a productive period in the restoration of the Acropolis will close. I should like to emphasise the contribution of all the personnel of the works, the scholarly, the technical, the support personnel, all of whom worked intensively in order to finish it. We gained valuable experience, we discovered secrets of our monuments, we enjoyed especially moving moments. The collaboration, the group spirit, the good working climate, the feeling that we were sharing in the therapy of the problems of the monuments reinforced our efforts. I thank them all from my heart for their effort.

Inestimable also was the contribution of the ESMA to the successful completion of this great undertaking. To the ESMA is owed the development of the principles and methodologies of the interventions, elements which, with the use of knowledge and experience from previous years, provided the driving forces of the work. Yet throughout all this time from 2000 to today, the ESMA was always close beside the work. With frequent meetings (over 200), many of which took place upon the rock, the Committee faced the problems that surfaced continuously in so large and difficult a work: problems of theory and of principle, scholarly research and technological application, problems in the choice of materials and procedures. And we should emphasise, I think, that the contribution of the members of the ESMA was totally lacking in self-interest all those years.

I cannot fail to separate the special contribution to the Acropolis works by the President of the ESMA, Emeritus Professor Charalambos Bouras. His deep scholarly knowledge, his international prestige, his insistence on scholarly consistency and interdisciplinary collaboration, his unceasing interest in the works, which was never lessened by adversities or difficulties, all contributed so that today his name is synonymous with the works of the Acropolis. For myself, I have special reasons to thank him. For the trust that he showed me from the beginning, when I assumed the coordination and carrying out of the work, his continuous support and encouragement through all the difficulties, his valuable advice in solving the problems. For all the above, but for even more, I thank him specially.

I should like to end this talk with a message of hope. The YSMA, a special Service of the Ministry of Culture and Tourism, using strict and totally transparent procedures –in the accomplishing of the works, in the choice of personnel and in managing the funds– with intensive work, pleasure and enthusiasm

The "Scattered Architectural Members" team move an inscribed block. Photo E. Sioumpara, 2009

Cleaning the coffered ceiling of the south porch of the Erechtheion using laser technology. Photo G. Frantzi, 2009

completed a vast work of real quality, a work that places our country in the vanguard of the field of restoration. Programmed for the coming years are interventions on areas of the monuments that show signs of structural problems, with funding from the National Strategic Reference Framework (NSRF). Despite the adverse economic situation, the State has declared its intention to support the Acropolis works economically.
In the vortex of the unknown developments we are now experiencing, I venture to wish that the works of the Acropolis may continue in the coming years with the same rhythm, the same creative spirit and enthusiasm that characterised the period that is ending. In this effort the driving forces will be not only knowledge and experience but the fulfilment that comes from contact with these magnificent monuments, feelings that make the labour a work of joy and which make us proud that we are Greeks.

Maria Ioannidou
Civil Engineer
Director of the YSMA

Text of lecture given for the Friends of the Acropolis on 6 May, 2010.

A stage in the cleaning of the coffered ceiling of the Erechtheion south porch using laser technology. Photo A. Maridaki, 2009

Educational Activities
In 2009, the Information and Education Department of the YSMA organised 120 educational programmes for 2,750 pupils of the 4th, 5th, and 6th grades of the Primary and 1st Gymnasium. Between January and June, 63 educational programmes for 1,620 school children were held in the Centre for Acropolis Studies on the theme "Let's go to the Acropolis" and between October and December 57 educational programmes on the subject of "The Parthenon Sculpture" were held in the new Acropolis Museum, attended by 1,130 school children.
The Department's museum kits went on loan to 200 schools (576 sections) from 12 prefectures throughout Greece and were used by 11,560 school children.
Likewise during this past year, the Department held seminars for 1,880 people, educators and students who were also given educational material. Most of the seminars were on the subject of "Educational Programmes about the Acropolis and the New Museum".

In 2009, in collaboration with the National Documentation Centre (EKT) of the National Hellenic Research Foundation (NHRF), a digital application on the "Parthenon Frieze" was completed for the Internet (www.parthenonfrieze.gr) providing open access to the frieze both for specialised scholars, as a database, and for schools and children through digital games. The presentation of the application on the web was accompanied by enthusiastic publications in both the printed and digital media (14 printed publications, 33 electronical). To this may be added notices in 17 blogs.
The website **www.parthenonfrieze.gr** receives an average of 12,000 visits per month (2,500 visits are from abroad). From June to December 2009 the digital application recorded 43,680 visits, 12,000 of which came from 115 different countries. The average length of time per visit is 9 minutes with an average of 12 pages per visit.
The digital material of the application will soon be entered in the depository of the National Documentation Centre, the purpose being the greatest possible diffusion through the network and its incorporation in EUROPEANA - The European Digital Depository of Cultural Heritage.

Educational programme in the Acropolis Museum. Photo C. Hatziaslani, 2009

Cover of the educational booklet "The Parthenon Sculpture". Photo S. Mavrommatis

Finally, the Information and Education Department of the YSMA carried out a series of activities in the context of the first operating year of the New Acropolis Museum, such as: organising the Museum Educational Centre, guiding tours for some 450 people between July and December, and publishing the educational booklet entitled "The Parthenon Sculpture" in Greek (22,200 copies) and in English (5,000 copies), that is used in the programme on the same subject in the Museum. A 13-minute movie in Greek and English was made about the Parthenon and its sculpture, entitled "Parthenon" and shown outside the Parthenon gallery, as well as a new version of the film for children up to 12 years of age that is shown outside the educational centre as an introduction to the educational programme "The Parthenon Sculpture".

Events
The most important event of the past year was, undoubtedly, the completion of two great restoration programmes of the Acropolis monuments. Completed in 2009 was the restoration of the ceilings of the central building of the Propylaia and, a few months later, the restoration of the north side of the Parthenon. With the scaffolding removed, the monuments were presented to the general public, the damage inflicted by earlier interventions now rectified and with improved aesthetic appearance, as a result of their systematic and scientifically correct restoration. The event was celebrated with an official ceremony in which the works were handed over to the President of the Greek Democracy, Mr. Karolos Papoulias, on Tuesday, 25 May 2010 at 10 a.m. The President of the Democracy was received by the Minister of Culture and Tourism, Mr. P. Geroulanos, the General Secretary of the Ministry of Culture and Tourism, Dr L. Mendoni, the President of the ESMA, Prof. Ch. Bouras, the Director of the YSMA, Mrs. M. Ioannidou and the Head of the 1st Ephorate of Prehistoric and Classical Antiquities, Dr A. Mantis. Also present at the event were members of the ESMA, scholars who had been members of the Committee in the past, members of the Ministry of Culture and Tourism, and personalities from other fields. After the official guided tour by the YSMA Director, those present had the opportunity to walk around the monuments and to see the two small photographic exhibitions that had been erected in the archaeological area and which contained information about the history of the restoration and the works performed on each monument. The event unfolded in a climate of enthusiasm and pleasure over the successful completion of such an important enterprise. Contributing also was the presence of YSMA personnel and also of colleagues who had

The President of the Hellenic Democracy, K. Papoulias, is guided through the Acropolis monuments by the YSMA Director. To the right, the Minister of Culture and Tourism, P. Geroulanos and the General Secretary of the Ministry, L. Mendoni. Photo T. Souvlakis, 2010

taken part in the past in the works of restoration, participating –in greater or lesser degree– in their successful completion.

The one-day conference on contemporary technologies in the restoration of the Acropolis, held by the YSMA in the Acropolis Museum on 19 March, 2010, presented to the scholarly community the important work of geometric documentation and geodetical monitoring of the monuments and the Acropolis rock that has been carried out during recent years. The conference was greeted by the General Secretary of the Ministry of Culture and Tourism, Dr L. Mendoni, and the President of the ESMA, Prof. Ch. Bouras. On behalf of the YSMA, talks were given by M. Ioannidou, D. Mavromati, Y. Alexopoulos, V. Eleftheriou, V. Manidaki and D. Egglezos, with S. Tsigani speaking on behalf of the Operational Programme "Digital Convergence" of the Information Society. The outside collaborators of the YSMA were likewise invited to report the results of their work. The following spoke: V. Tsingas, Ch. Liapakis, L. Grammatikopoulos, I. Kalogeras, G. Stavrakakis, N. Melis, D. Loukatos, K. Boukouras, V. Astreinidis, T. Iliopoulos, I. Partsinevelos and S. Leloudas. There was strong public response and the amphitheatre of the Acropolis Museum was full to overflowing. This shows the active interest of the public in issues concerning the protection of the Acropolis monuments. The Proceedings of the Conference are published in the present fascicle of the Acropolis Restoration News.

The President of the Hellenic Democracy, K. Papoulias with the Parthenon team. At the right is the President of the ESMA, Ch. Bouras. Photo T. Souvlakis, 2010

An event of particular significance which interested the wider public as well, was the series of interviews on the subject "Dialogues on the Acropolis" organised by the SKAI radio station. Scholars from the YSMA took part. The interviews were conducted by A. Portosalte and aimed at a spherical approach to the monuments of the Acropolis. The following spoke on behalf of the YSMA: T. Tanoulas on the Propylaia of the Acropolis; M. Ioannidou, N. Toganidis, T. Tanoulas and the marble technician G. Desypris on the modern restoration of the Acropolis; F. Mallouchou-Tufano on the Acropolis of the 19th and 20th centuries and on the documentation and archaeological and historical research of the modern restoration of the Acropolis; E. Papakonstantinou-Zioti on the conservation of the surface of the Acropolis monuments and C. Hatziaslani on the educational programmes on the Athenian Acropolis. Many other prominent scholars took part in this series of interviews: the President of the ESMA, Prof. Emeritus Ch. Bouras, who spoke on the Acropolis in Byzantine and post-Byzantine times and about the theoretical principles of the modern restoration of the Acropolis; the ESMA members Prof. M. Korres, on the conditions and the framework of creating the miracle of the Acropolis, on the golden age of Pericles and the Parthenon and on Athena's worship and the semiology of the monuments of the Acropolis; also D. Giraud, who spoke about the Temple of Athena Nike; the head of the 1st Ephorate of Prehistoric and Classical Antiquities, A. Mantis, who spoke about the Acropolis Museum and the President of the Administrative Council of the Acropolis Museum, Prof. D. Pandermalis, likewise on the Acropolis Museum; the former Ephor of the Acropolis, D. Tsakos, on the sanctuaries and cults on the hill of the Acropolis; the former Director of the YSMA, K. Zambas, on the beauty of the monument and the first years of the restoration of the Acropolis and moving the sculptures from the old to the new Acropolis Museum; Prof. P. Valavanis on the Parthenon frieze and the Director of the Ministry of Culture and Tourism, E. Korka, on the pillaging of the Parthenon Marbles by Elgin. The interviews have been published in a book entitled "Dialogues on the Akropolis: scholars and experts talk on the history, restoration and the Acropolis Museum".

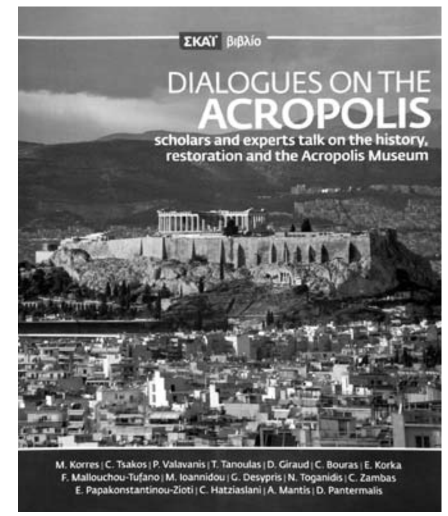
As every year, this year too, the Acropolis Friends (EFA) made their visit to the Acropolis works. On the May 7th, 2010, the members of the Acropolis Friends were guided through the Acropolis monuments by the YSMA Director, Mrs. M. Ioannidou. They thus had the opportunity to admire the monuments after completion of the works and removal of the scaffolding and to be informed about the progress of the works being carried out at present. This was preceded by a lecture given for the members of the Acropolis Friends on May 6th, 2010, by Mrs. Ioannidou, on the progress of the restoration works. The lecture is published in the present fascicle of the Acropolis Restoration News.

To conclude, we must mention that the exhibition of the YSMA photographer S. Mavrommatis, was included in an expanded, more varied exhibition entitled "Athens: a living history", organised by the Ministry of Culture and Tourism in the Library of Shanghai, China. The exhibition, in the framework of the cultural activities of Greece in the Worldwide Shanghai Exhibition, was inaugurated on the June 11th, 2010 by the General Secretary of the Ministry of Culture and Tourism, Dr L. Mendoni. On this occasion, Mrs. Ioannidou guided the prominent visitors through the exhibition of the Acropolis works.

Lectures - Publications

During the past year, as usual, the scholarly personnel of the YSMA gave lectures, read papers at symposia or published articles in professional journals about the A::s monuments and the works of anastelosis.

In addition to the activities reported above,



Cover of the book "Dialogues on the Acropolis" (SKAI 2010). Photo E. Bardani, 2010

M. Ioannidou contributed an article "The restoration of the Acropolis" to a special publication of the newspaper "Ta Nea", entitled "Acropolis: from the Monuments to the Museum", which circulated on the occasion of the opening of the new Acropolis Museum. On the December 9th, 2009, T. Tanoulas gave a lecture at the Archaeological Society entitled "The Propylaia of the Athenian Acropolis and its environs". He lectured on the same subject also at the Yearly Educational Seminar of the Union of Guides on the February 26th, 2010. The Conservation section was particularly active: E. Papakonstantinou-Zioti addressed a Seminar organised by the British School on the subject of "Paint on the Parthenon Sculptures" on December 14th, 2009. Likewise, the YSMA conservators G. Frantzi, A. Panou, A. Tsimereki and K. Frantzikinaki gave a paper on the subject "Monuments of the Acropolis: the programmes of surface conservation and the general activity of the conservation section during recent years" at the one-day conference of the Panhellenic Association of Antiquities Conservators, 5 December 2009. On March 1, 2010, L. Lambrinou gave a lecture at the Architectural School of the University of Notre Dame, South Bend, USA, entitled "Preserving a Monument: Principles and Implementation". An article by the same author, entitled "Preserving a Monument: the Case of the Parthenon", is to be published in Vol. 10 of the journal Conservation and Management of Archaeological Sites. K. Karanasos took part in the International Museological Seminar "Premio Piranesi-Prix de Rom" that was held in Rome on 4 September 2009. The subject of his lecture was the restoration of the Propylaia. He likewise participated in the 8th Symposium on the Protection of the Monuments of the Mediterranean (Monubassin 8) that was held in Patras (31 May to 2 June 2010). The title of his paper was "The restoration of sixteen authentic blocks of the superstructure of the south wall of the Propylaia".

To conclude we should report that the year that passed saw significant changes for one of the first members of the Acropolis works, the head of the Documentation Office, F. Mallouchou-Tufano. On September 22nd, 2009, her services in the YSMA came to an end as she was appointed Associate Professor in the Architecture Department of the Technical University of Crete, in the field of History and Theory of the Restoration of Monuments. As a member of the ESMA, however, she continues to contribute her knowledge and experience to a project she served productively for more than thirty years.

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Details of an orthophotomosaic of the Beulé gate.
Study for the development of GIS on the Acropolis of Athens, 2009

Details of an orthophotomosaic of the north Wall of the Acropolis.
Study for the development of GIS on the Acropolis of Athens, 2009

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