A Spatial Information System for the Archaeological Site of Mycenae
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Digital and automated photogrammetric procedures, developed for the collection and management of spatial data, and terrestrial laser scanning systems provide new capabilities for documentation of archaeological monuments and sites. Also, special tools in Spatial Information Systems and production of virtual models have been developed. Their combination provides relevant scientists (architects, archaeologists, etc) and users with a variety of options for the creation of integrated systems capable for documentation, restoration and cultural development of archaeological sites. Detailed 2D and 3D representation of the current condition of the site, development of a multi-purpose SIS, and introduction of modern digital products at a local museum, such as 3D models, creation of virtual environment and Web applications are some of them. Application of such techniques and systems was made to the archaeological site of the Mycenae in Greece, one of the most important sites worldwide.
1. Introduction

The collection, processing, management and visualization of spatial data are the core area of research activities and application fields of all methods and techniques of geoinformatics. As digital and automated photogrammetric methods develop their application possibilities increase, always in combination with other techniques which are developing in parallel with a higher or lower ratio, such as laser scanning, GPS and others. The geometric recording and documentation of monuments or archaeological sites, which usually are complicated constructions with a demand for detailed data, was the traditional privileged application field of photogrammetric methods. The recent developments offer additional new alternative techniques, systems and methods. The need for integrated surveys and documentation of the archaeological sites, more quickly and with greater details, have increased radically. The compilation of horizontal plans, facades, and intersections consist of only a necessary layer. These should be integrated with raster products, 3D representations, thematic maps, images, textual information, video, audio data, reconstructions, animations, movement in virtual environment etc. to mention some of the continuously increasing list of possibilities.

The first step of the documentation process is to structure all the above-mentioned data into a Spatial Information System. This is not a new demand and the basic principles for a SIS structure for archaeological sites have been already analyzed and applied, e.g., [1], [2], [3], [4], [5]. The new demands and the new data sources, such as the terrestrial laser scanners of high accuracy, the virtual model products etc., lead to the use of improved methods for data management and especially for data visualization. According to the user of the system (specialized scientist, visitor to the site, tourist) the level of access to the systems’ data and the data visualization methods should vary. Major challenges to be faced are:

• To avoid unreasonable integration to the SIS of all kind of existing data simply because they are related to the monument.

• To use the SIS as a decision making tool to manage and recreate the archaeological site or to support the research and excavation work. Special mention should be made of the new capabilities provided by the integration of digital re-creation of 3D shapes of buildings and objects to the archaeological SIS. The creation of virtual environment, with digital representations of objects according to some hypothesis about how the site was constructed at particular historic periods, or the construction of virtualised environments by modeling existing small or big objects of the physical world, offer the possibility of expanding the capabilities of a specialist in planning, creating and experiencing new surroundings [6]. At the same time, the use of the Web allows the individual to visit, as a virtual tourist, a remote site or various sites that are not accessible by the public.

An application of all the above mentioned ideas was made for the archaeological site of the Mycenae in Greece, one of the most globally important sites. Mycenae, located 150 km southwest of Athens was the most
important and the biggest center of the prehistoric Hellenism during the second millennium BC. Habitation there started since 19th century BC. The most developed period of Mycenae was between 1300–1100 BC. It was re-inhabited at about 1000 BC, destroyed by invaders from Argos at 468 BC, a new Hellenistic city was established during the 3rd century BC and Mycenae continued its existence until the Roman times when it was finally abandoned.

The site includes the Citadel, an area of 3.2 hectares surrounded by Cyclopean Walls and containing ruins of palaces, temples, houses, etc. and the famous Lion Gate which carries the first known sculpture in history. At the western and south-western side of the Citadel there is an area of approximately 60 hectares, which has significant archaeological findings, mainly graves of great art and store-houses. There are more than 250 graves in cemeteries [7] and 9 large tholos tombs (each of them consists of the dromos and the chamber); the most impressive and better preserved one is the Treasure of Atreus, which was constructed by large blocks of ashlar conglomerate. The chamber consists of 33 ring stones, with a diameter of 14 m at its base and a height of 13.50 m. Another special characteristic element is a number of movable findings of excavations and mainly the golden objects that were found inside the graves, which are now stored away from the site; most are displayed at the National Archaeological Museum of Athens, in Greece.

An integrated approach for the presentation of all data of such an important archaeological site, demands:
• The detailed 3D documentation of the present condition of the site.
• The development of a multi-purpose archaeological SIS, to be used by professionals but also by visitors to the site.
• The enrichment of the local museum with digital products which can be produced by modern technology (VR, Web applications).

2. Geometric documentation of the site of Mycenae

The optimal approach, from technical and economic point of view, for the complete 3D documentation of the archaeological site of Mycenae is the combined application of automated digital photogrammetric methods (using large scale aerial photos and terrestrial images), with field surveys (using GPS and conventional means) and with the use of terrestrial laser scanners (both time-of-flight type for large surfaces as well as triangulation type for small objects). A variety of vector and raster (orthophotos and texture mapping) products in 2D and 3D for the whole archaeological site and especially for the Citadel and the tholos tombs can thus be produced. Detail plans of high geometric accuracy for the most interesting parts, colored raster facades of the Cyclopean Walls, developments of the interior of the chambers domes, intersections and horizontal plans are the main 2D products. The products of 3D virtual and augmented reality animations of selected monuments or the whole site are even more impressive.
2.1. Photogrammetric procedures

The total number of aerial photos taken for the full coverage of the archaeological site, from a helicopter capable to carry the large format metric camera UMK 13 × 18 Zeiss of a focal length $f = 100\ mm$, was:

- 45 photos in 6 strips, at north-south direction, at a scale of approximately 1:2,000.
- 6 photos, at scales varying between 1:500–1:1,000, for the coverage of significant elements lying inside the Citadel (palace area, grave circle A’, etc).
- 7 photos in 1 strip, at a scale approximately 1:600, for the coverage of an area which contains store houses and lies at the south-western side outside the Walls.
- 3 overlapped photos for each of the tholos tombs, at scales 1:200–1:300.

In addition to the above, a large number of terrestrial photos were taken, by analogue and digital cameras of varying formats and focal lengths. The facades of the most significant monuments inside the Cyclopean Walls and the internal facades of each tholos tomb were also photographed.

Twenty five control points were measured by GPS for the processing of the approximately 50 stereomodels created by the aerial photos. The coordinates of 150 more control points were calculated by bundle adjustment aerial triangulation, using the BINGO software. A detailed DEM was automatically compiled and breaklines were manually digitized for the whole archaeological site, using the SoftPlotter of Autometric Digital Photogrammetric Workstation. The production of orthophotos and the compilation of orthophoto-mosaic for the whole site were made (Figure 1).

![Figure 1: Orthophoto-mosaic of the archaeological site, with the Citadel at the right (some of the major monuments are marked).](image-url)
Also, detailed 3D vector restitutions of all stereomodels, 3D views of vector data (Figure 2) and planimetric plans were produced.

For the orientation of the terrestrial images, a large number of pre-signed control points were measured by conventional field surveys. Rectifications and stereo-restitutions for the compilation of raster and vector products (facades and sections) were made at the photogrammetric station ARCHIS PLUS (modules Archis and Stereometric). The production of orthophotos for the facades of the important archaeological monuments is of special interest. The use of commercial software available with DPW gives products of low quality and accuracy or it could not be applied at all, due to the complexity and the shape of the monuments, e.g. for the interior of the chamber of a tholos tomb, whose surface is composed by successive cones. In order to solve this problem a special software was developed (in MatLab environment) which gives excellent results (Figure 3). Also, through...
in-house written software the creation of developments was attempted for monuments whose surfaces are developable (Figure 4) [8].

2.2. Additional field surveys

Data and spatial products of the above mentioned photogrammetric techniques were completed by conventional field measurements in situ. Specifically this was done for the locations where either photogrammetric techniques could not be applied, e.g. for underground cisterns, or a more detailed recording was needed, e.g. for wall foundations which can only be defined by field observations. The result is the collection of a large volume of additional data (more than 12,000 points measured inside the Citadel) which provide information about the existing situation at the site, with an accuracy which varies from 1:50, for the significant monuments, up to 1:500 for the surrounding area. The above and the photogrammetric data provided the basis from which the 3D vector model of the existing constructions were compiled using semi-automatic methods [9]. Figure 5 shows a part of the
triangular network (TIN) which was created from all available information and Figure 6 shows an axonometric view of the present condition of the Palace and the surrounding area. Finally, Figure 7 shows a 3D augmented reality scene with a representation of the palace (according to the proposal of Mylonas & Papadamtriou [10]) and a draping of the orthophoto-mosaic of the produced dense digital surface model (DSM) of the site. Such representations, based on the products of the geometric recording, have allowed the production of a video animation recording along the periphery and inside of some significant monuments by using 3D Studio MAX and LightWave 8.1 of Newtek software.
2.3. Terrestrial laser scanning

Since their introduction in the mid 1990s, the 3D terrestrial laser scanning systems with the ability of quick, accurate and reliable recording of huge numbers of points (point clouds) at the surface of the objects has been applied in the recording of historical monuments. The first initiatives and the successful development of some prototype instruments [6] were followed by the production of scanners by various companies. There are mainly three types of scanners that fit with our interests:

- **Time-of-flight scanners**, modulated beam or pulsed laser (such as: 3DTech, HDS ScanStation, Optech ILRIS 3D, Riegl LMS-Z390), with a maximum range of 100 m up to 1,200 m and accuracies up to 4 mm. They are appropriate for scanning large surfaces from medium or long distances, and they have been used for scanning building facades, fortification walls, for the documentation of archaeological excavations ([11]), etc.

- **Phase difference scanners** (such as: FARO LS, Z+F Imager5006) with a range up to 75–80 m, FOV larger than 270° × 360° and capability for fast recording of large number of points (150,000 – 500,000 points/sec).

- **Triangulation scanners** with one or two CCDs (such as: Minolta Vi-9i) for very high accuracy scanning (0.1 mm) but limited range (usually up to 2 m). These are appropriate for scanning of complex objects of small size, such as sculptures or 3D decorations [12] and moveable artefacts [13].

Laser scanning applications at the Mycenae refer to the:

- Cyclopean Wall which surrounds the Citadel, with 980 m perimeter length and with 7.5 m maximum height.
- Palace, with 200 m perimeter length and 2–6 m height.
- Stelae at the upper part of the Grave Circle A.
- Internal side of tholos tombs.
- Internal surface of the cistern.

In all these cases, except for the last one, the most appropriate scanner type is the time-of-flight scanner. The HDS2500 of Leica (FOV 40° × 40°) was used and a full coverage scanning series of the Tomb of Atreus were made, which covered the chamber, the doorway, the dromos and the surrounding area. Thirteen scans were made for the internal of the chamber and 8 scans for the external, in two days, using special targets whose coordinates were measured by field surveying. Registration and merging of the data was made by CYCLON software. The point cloud produced (Figure 8 Left) was used for the production of orthophotos, the 3D model of the tomb using the Geomagic software (Figure 8 Right), and finally a photorealistic product in Lightwave (Figures 9 Left and Right).
3. Spatial Information System

3.1. Structure of the system

To develop the archaeological SIS of the Mycenae, the ArcGIS v9.1 of ESRI with the extension 3DAnalyst was used, which provides excellent tools for 3D visualization, animation and navigation through 3D textured models. The structure of the system was based on the purpose that it should be usable both by tourists/visitors of the archaeological site and by professionals, who study the development of the site and the restoration of damaged parts of the monuments and experts, as well. As a result, a tree-structure was developed which can be further enriched with data and information. The access to the data of the IS can be achieved by the following five alternative ways:

- Vertically from general to specific. Figure 10 gives a schematic development of the SIS based on this access method, with an example of a search path for data that refer to a particular monument of the “Late-Helladic period”.
- Through specific to the general, i.e. from a thematic characteristic of a monument, predefined to a menu, to the selection of all other monuments of the site which have the same characteristic.
Figure 10: Structure of the SIS content, by using vertical access to the data.
• Sequentially, following a predefined path of SIS ‘screens’, for a user-friendly access to the basic information by the tourists.

• By choosing a key element, i.e. some thematic, time period, quality or other characteristic, from menu of available information. There is a capability of selecting a monument according to a thematic categorization (such as “tholos tombs”) or chronological reference (i.e. “Late-Helladic”) or a combination of characteristics (i.e. “Late-Helladic tholos tombs”) or a quality characteristic-choice from a menu (i.e. “Existence of reconstruction plan”).

• Through correlation of similar characteristics of various monuments, i.e. linkage to different kinds of information or to other monuments of the site.

The installation of information kiosks, with computers with data and software of the SIS at the entrance and other locations within the archaeological site and also at a specific place inside the local museum, will contribute to the better service and information of the tourists.

3.2. Data of the system

Data that have been inserted and are managed by the SIS include generally:

• All products of the detailed geometric documentation, as they are described above, i.e., 2D plans and 3D views at various detail levels, time periods and historic phases.

• Texts derived from historic sources and literature ([10], [14], etc).

• Digital images, derived from recent and old photos of the site (Figure 11) and of the excavations, or old graphic representations.

• Visualization of tour paths, with predefined walk-through and flyovers, and video of virtual and augmented reality.

Figure 11: Old photo of the excavations, during 19th century, at Grave Circle A.

Figure 12 shows a screen which is derived through a proper access into the SIS and data combination of geometric documentation, textual description and photos (aerial and terrestrial) of a tholos tomb.
Figure 13 shows windows with 3D views derived from a virtual fly-over of the Citadel and a walk-through around the Grave Circle A, which are produced by 3D Studio MAX software for model visualization and Adobe Premiere for video producing and editing.
4. Geoinformation in the local museum

The local museum of the Mycenae is housed in a building located at the north-western side of Citadel, close to the tomb of Lions. Despite the fact that the museum has opened for the public recently (2003), its structure and operation model is based on the traditional theories and on the display of existing exhibits. The current arrangement of the rooms of the museum is mentioned (Figure 14):

- At the entrance hall there is an exhibition with texts and photographs from excavations and excavators and a model of the Citadel.
- At the first room there are exhibits from houses sited inside and outside the Citadel.
- At the second room there are exhibits from the cemeteries. The most important part, the Grave Circle A, is missing since the finds from that part are kept at the National Archaeological Museum of Athens.
- At the third room there are exhibits from periods later than the Mycenaean era and some groups of the finds according to their use or their role in everyday life or in religious ceremonies.

The use of digital technologies and the amount of computer-compatible data generated, are a challenge to improve the operation of the museum and the structure of the exhibits, introducing novel approaches to archaeology [15]. By making good use of the new media [16] museums can now:

- Provide more information on the context related to the artifacts presented.
- Draw conceptual links between various artifacts of the museum’s collection or with other collections, using SIS tools.
- Provide 3D virtual representations of objects, which are too fragile to be displayed or which have been found at the excavations of the particular archaeological site but are displayed in other museums. Especially at the Mycenae, the latter is a real problem since all gold finds of great value, and other finds as well, are exhibited mainly at the National Archaeological Museum of Athens. So, at the local museum there is a large number of exhibits, approximately 1,600 pieces, but almost all of them are ceramics.
- Make complex phenomena more clear and understandable to a non-specialist audience. Digital representations and stereoscopic views in VR environments provide valuable tools.
- Trigger the interest of users normally not interested in archaeology, especially of children who are familiar with video games and the Web.
- Visualize different interpretation theories for professionals and researchers.

Based on the above, an integrated proposal has been developed for the museum, which combines the traditional operation model with the display
of products of digital technology [17]. This arrangement proposes the possibility of breaking the 'real' space into different spatial subunits, which will be related to its function (exhibits, public, information, other uses). A scenario is created about the type and level of multiple walk paths inside the museum. In order to solve the problem of the limited available space, a good use of its height is proposed: the visitor is smoothly led towards a suspended rising corridor, where the information either is provided by digital means or is mixed with the exhibits, thus creating space and virtual images which provide all necessary information for the better understanding of the site and its history (Figure 15).

In the following, two of the most interesting elements of the proposed applications to be used at the Museum, are briefly analysed.

![Figure 14: Plan of the Museum with the visitors' routes.](image-url)
4.1. Virtual 3D representation of the finds

An important contribution of digital technology to the design and organization of the local Museum relates to the approximately 500 artifacts of small size made of gold, copper, ceramic and other material, of various types and dimensions. These are finds of the archaeological site of Mycenae and they are either displayed in other museums or stored and not exhibited (examples are given at Figure 16). Besides simple photos, the only possibility to present them to the visitor is by showing their 3D digital representation at a computer screen. Each visitor will be able to choose the object of his/her interest, on the screen and observe it in space, selecting the point of view and the observation direction with a mouse or a joystick.

The complexity of the objects and the small dimensions of their details define the laser scanning as the only applicable technique for their documentation and digital modeling. Using a triangulation scanner, like Minolta VI-9i, data of good quality are acquired and integrated to the SIS. The cost of scanning and modeling of the main moveable finds of the Mycenae is affordable, since the work can be done gradually.
4.2. Museum and the Web

Recently, there has been an increasing confluence between museums, as social institutions with a certain historical tradition and mission, and the Web. Leading museums have introduced structures, technologies and business relations from the world of commercial organizations into the museum content management and have professionalized their Web operations. From the first Web period, when the Web was just a mean to advertise the museum, we passed to the second period, when the Web was an alternative venue in cyberspace to implement museum programs. Recently, the third period appeared, during which the Web can affect the fundamental nature of museums. Studies, initiatives and similar pilot applications are already available in the international literature ([18], etc).

In the local museums, like the one in Mycenae, the use of Internet is of vital priority for the promotion of the archaeological site, the 2D or 3D visualization of its objects and the e-business development for the sales of copies of finds. The existence of an SIS with the detailed geometric documentation of the site constitutes the best foundation for the implementation of such a project. Figure 17 shows one of the web-site screens which was created and operates for the archaeological site of Mycenae. In total...
five main entities are created: General, Historic data, Monuments, Museum and Links, and 36 sub-entities. These display all the significant monuments of the site inside or outside the Citadel, the content of the existing museum rooms and the proposed interventions on them by introducing products of digital technologies. In these entities there are vector and imagery products of geometric recording, 3D photorealistic models and video which are created as mentioned above, and also texts, photos, old images etc. It is possible to further enrich the web-site with new information keeping track of the further development of the SIS of the archaeological site of Mycenae.

5. Conclusion
The organizational and operational concept of archaeological sites, and the ideas about the structure and mission of museums have changed radically. For that reason their characteristics and the newly developing relation between museums/archaeological sites and their space and the public should be redefined. Through the technological developments in management and communication, an integrated archaeological Spatial Information System, including data of high quality and accuracy can be easily produced. The users of this SIS can be either professionals and experts or simple visitors and tourists, according to the accessibility facilities provided by the system.

This new situation creates a series of queries among some specialists which are used to look at things traditionally. Their concern refers to the correctness of the type and the way information is presented and the understanding of the difference between the image and the in-situ display, since these two cases are considered to be two concepts ruled by completely different principles. The Web as a potential threat to the on-site visit and the physical/reall museum is confronted by moving the virtual exhibition (located somewhere else, most often approached from somewhere other than the museum homepage) closer to the physical space; and by introducing the Web into the organisation and operation of the museum itself, and thus developing a “mixed reality”. No one doubts the potential benefits of such an initiative as long as this will be the result of cooperation between the public, academic and private sector. Much greater variety of data can gradually be integrated to a system as such. Traditional tools used for the organization and planning of a site which use common principles directly related to the archaeological research, such as hierarchy, centralization, continuity and relationship, can be applied only if they do not hinder the adjustability of methods and alternative ways for exhibiting; principles which are now necessary for knowledge and information sharing.

Another query and issue of discussion and skepticism is related to the kind of data that should be available, to whom and at what time, and how the past era is represented. By providing a very convincing visualization, there is a risk that users may think that there is an indisputable, single interpretation of everything. More research should be made to find how all
these can be done in a way that attracts attention to the artifact and enables, rather than inhibits, communication among visitors.

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