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SICAC: AN INFORMATION SYSTEM FOR THE *CONJUNTO ARQUEOLÓGICO DE CARMONA* (CARMONA ARCHAEOLOGICAL ENSEMBLE) (SEVILLE, SPAIN)

1. The *Conjunto Arqueológico de Carmona*

After several years of archaeological excavation and adaptation works for public visiting, Juan Fernández López, a pharmacist and local learned man from Carmona, and George E. Bonsor, a painter and archaeological amateur of Anglo-French descent, inaugurated the *Necrópolis Romana de Carmona* on May 24, 1885 (Fig. 1). It was the first time that an archaeological site was opened to the public in Spain and one of the first cases within Europe. Two years later an on-site museum was built to show the archaeological objects found inside the Roman tombs.

The *Necrópolis Romana de Carmona* turned part of the western necropolis of the ancient Roman city of *Carmo* into an open-air museum. This archaeological site is characterized by a type of burial consisting of cremation ashes kept in urns placed inside family-unit *hypogea* chambers accessed by a rectangular dwell-like opening. Besides this common type, other tomb types are found such as those with more complex floor plans in which the rectangular dwell-like opening leading to the *hypogea* chambers were substituted by large patios dug into the rock, such as the Elefante, Postumio, and Servilia tombs. Also common are *busta*, which are tombs located at the same site where cremation took place. These funerary complexes are dated from the end of the first century BCE to the middle of the second century CE.

López, Bonsor and other members of the *Sociedad Arqueológica de Carmona*, a private cultural institution whose purpose was to promote archaeological research in Carmona and its surrounding area, excavated almost 500 tombs, from which only about two dozen were open to the public at the time. The *Necrópolis Romana de Carmona* underwent a new period of excavation between 1970 and 1983. During these years the amphitheater, most of which was carved into the rock (*ima cavea,* podium, and arena) and dates from the middle of the first century BCE, was opened to visitors. Additionally, almost a hundred tombs found around the amphitheater were excavated. The first restoration works of tombs, of which documentary evidence remains, took place during that decade.

In 1984, administration of the *Necrópolis Romana de Carmona* was transferred from the State to the regional government of Andalucía (*Junta de Andalucía*), the governmental agency of the Autonomous Community of Andalucía, which in 1992 created an administrative service dedicated to its

Fig. 1 – Aerial view of the Carmona Archaeological Ensemble.

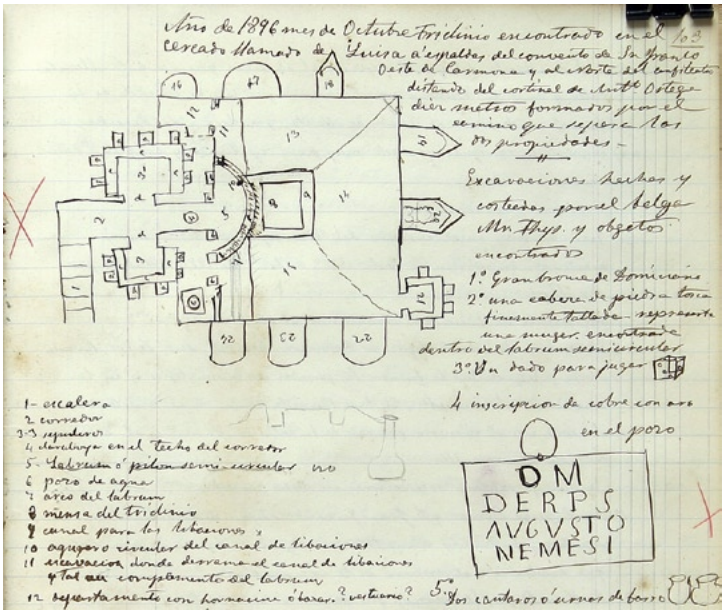

Fig. 2 – Carmona Archaeological Ensemble archive. Excavation book.

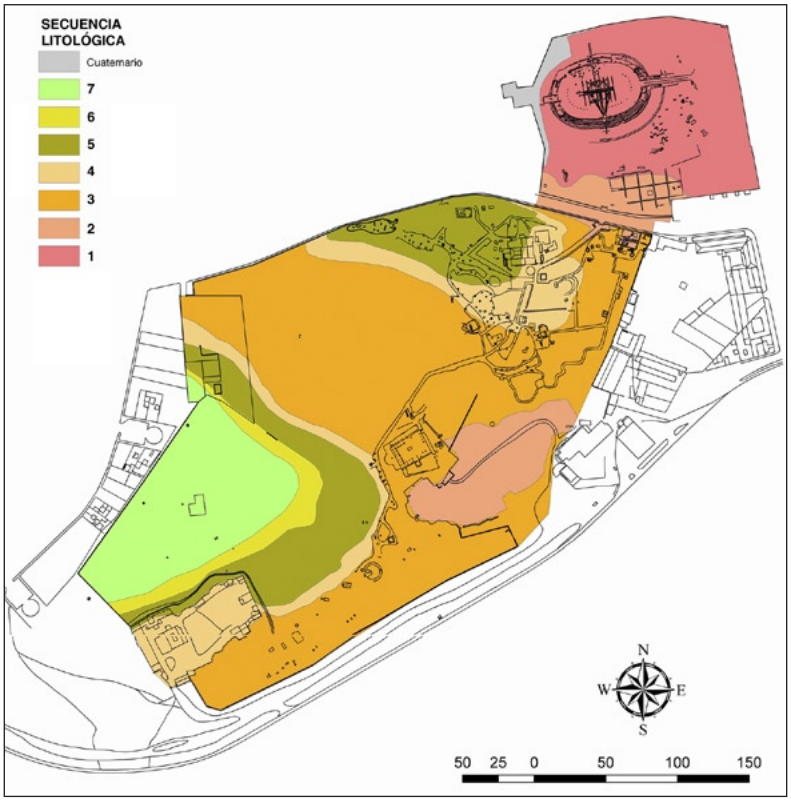

Fig. 3 – Geological mapping of the Carmona Archaeological Ensemble.

management and changed the name from *Necrópolis Romana de Carmona* to *Conjunto Arqueológico de Carmona* (hereinafter CAC). With over 125 years of existence, the CAC administers an archaeological site measuring approximately 60,000 m^2 where 352 funerary structures, the amphitheater, and some Roman-era quarries are preserved. In addition to this real estate, the on-site museum contains several hundred objects that have been found inside the tombs, especially funerary urns, grave goods, epitaphs and other articles related to funeral rites.

The legacy that CAC preserves also includes a historic and very broad archive of enormous historiographic value. This documentary collection is composed of the archives from two different sources that are closely related: the *Necrópolis Romana de Carmona* and the *Sociedad Arqueológica de Carmona* (CAS). Right from the start of their excavation work, López and Bonsor were meticulous preservers of all of the documentation they gener-

ated, which now belongs to the museum (Fig. 2). For its part, CAS held their meetings at the library in the museum itself, to document their field trips and special sessions, which are all recorded in the minutes and preserved in the archive that they created for this purpose. The two institutions, from 1884 to 1909, produced a vast archive with the original documents from the archaeological digs at the end of the 19th century: excavation logs, sketches, drawings and architectural diagrams of tomb sites, photographs, maps of the entire excavation site, copies of the paintings that adorned the tombs (now lost in many cases), and the meeting minutes and notes from digs and field trips undertaken by the members of CAS.

Additionally, CAC has an administrative archive that was initiated in 1930, although from 1931 to 1965 there is a gap in documentation. This archive conserves information that is valuable for managing the CAC: restoration reports, scientific studies on the pathologies affecting the host-rock of the tombs (Fig. 3), projects for adapting the spaces open for public visitation that were never carried out, recent studies on the weight-bearing capacity of visitor traffic around the site, and surveys of the visiting public. This entails a huge volume of information that is enormously varied not only in nature and purpose but also in the types of media it is recorded on, making it difficult to manage the complete data set for purposes of information-based decision-making.

2. Objectives of SICAC

In 2005 a large project was undertaken to create a user-friendly digital tool that would manage and integrate this great volume of data in its multiple formats (text, photographs, planimetric, and cartographic), into a single system that would provide easy access and interconnection of the information, called SICAC (*Sistema de Información del Conjunto Arqueológico de Carmona*). SICAC was created to address several CAC-management objectives.

1) Management: to create a system to unify all the information generated by CAC to facilitate maintenance and decision-making.
2) Preservation: to preserve archaeological documentation under the custodianship of CAC by digitizing its entire collection; to create a virtual replica of all of the archaeological structures.
3) Research: to integrate and interconnect all the information on the older excavations and the new ones, including a system for recording stratigraphic units; to use GIS tools for geographic, archaeological and predictive analysis of CAC.
4) Knowledge sharing: to possess instruments for planning activities aimed at sharing knowledge about CAC's archaeological value, adapted to the demands of a diverse public; for interested researchers, to facilitate online access to the archaeological information.

This work was commissioned to a company with experience in applied geometrics, TCA Geomática, S.A., who performed the work in conjunction with CAC staff. TCA Geomática, S.A. performed surveys of over 300 cultural heritage elements, including but not limited to the topographical mapping of important archaeological sites in Andalucía such as *Baelo Claudia* and *Carteia* in the province of Cadiz and in the province of Sevilla, *Cruz del Negro*, *La mesa de Setefilla, Arva, Celti* and the *Alcázares* of Seville.

3. The process of creating SICAC

3.1 *Inventorying, cataloging and digitizing the documentary collections*

The oldest archival instruments that we conserve are inventory lists from circa 1900, related to the work of the CAS. The oldest inventory of "Books and documents existing in the Archive of the Necropolis" dates from 1906. In 1925, an inventory of goods existing in the museum was carried out, although it is rather incomplete. From 2005 and 2006, inventorying, cataloging, and organization of the historic archives of CAC as well as the administrative archives and the CAS library archives were conducted in compliance with international ISAD-G standards. Once the archival collections were organized, they were digitized in their entirety. The archive stores the documentation generated by the *Necrópolis Romana de Carmona*, the *Sociedad Arqueológica de Carmona*, and the *Conjunto Arqueológico de Carmona* over the course of their work. Notable among the documents are those related to the commencement of the management of the monument, the original manuscripts on the digs, documents belonging to the *Sociedad Arqueológica de Carmona*, the correspondence library and the photo library. Complementary to the work produced in terms of inventorying, cataloging and digitizing the archival collections, there exists a specific analysis of the bibliography generated by the Roman Necropolis of Carmona, to be incorporated into the pool of information.

Special attention has been paid to the photo library. CAC manages photographs from two different sources. One is historiographic and is composed of three different collections: the *Archivo General de Andalucía*, the *Museo Arqueológico de Sevilla* and CAC's own historical archive (Fig. 4). The other source consists of the activity of preservation, research and knowledge sharing that is CAC's daily work. At the center of the collection of the old photographs is the Bonsor collection belonging to the *Archivo General de Andalucía*, that had previously been digitized. The collections of the *Museo Arqueológico de Sevilla* and those of CAC have been digitized and recently published in a monograph. With respect to CAC, a database of digital photographs have been created consisting of photos that are taken at the site on a daily basis,

Fig. 4 – Carmona Archaeological Ensemble archive. Historical photographs.

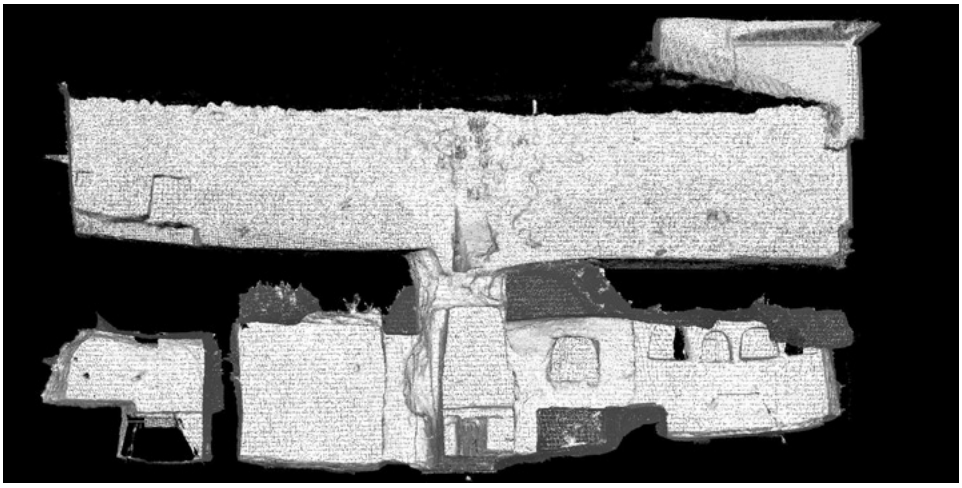

Fig. 5 – The Elefante tomb.

numbering nearly 13,000 images. This database has been linked with CAC's archaeological structures. Another task of extreme importance has been cataloging, inventorying and creating a database of all the archaeological material existing in CAC's storerooms. The difficulty is due to the sheer quantity of

items that it contains and the complicated work of linking the materials to the funerary structures they belong to, since the references were lost during the extraction process for a great many of them.

3.2 *Capturing geographic data*

As to the basis for SICAC, a precise topographic grid of the entire archaeological complex linked to the National Geodesic Grid is the foundation for this project and projects to be carried out in the future. A complete digital planimetric mapping of the entire site has been undertaken, updating and expanding a previous planimetric survey from 1993. Using a tachymeter, new points have been taken of all the surface archaeological structures that link the surface with the *hypogea* chambers. These are features or visible traces on the surface that denote the possible existence of *episemata* in the exterior of the funerary complexes. A high-resolution Digital Terrain Model (DTM) has been created from aerial photogrammetry conducted during an *ex profeso* flight for this project in 2010.

The flight was ortho-rectified, resulting in an image with a resolution of 5 cm/pixel that serves as a foundation for geographical analysis with GIS tools. The largest investment in work and resources for SICAC was in the laser scanner survey of the entirety of the archaeological structures. A total of 225 underground funerary structures and 127 surface features associated with them were scanned, in addition to the amphitheater. The result is a virtual replica of all the archaeological structures presently visible at CAC (Fig. 5). In round numbers, over 6000 work hours were spent on capturing 1800 laser scans, producing an output of around 40 billion points.

3.3 *Integration of specific studies*

Included in the processes of developing SICAC were a number of research studies conducted for the purpose of understanding different aspects of CAC. These will be useful for daily management activities.

– Archaeological analysis of the funerary structures. Despite having been excavated at the end of the nineteenth century, CAC did not have an inventory describing the funerary structures using archaeological methodology, documenting the different constructive and destructive phases of each dig, nor their chronological order or sequence. As has been mentioned, only occasionally has it been possible to correlate the archaeological relics found in the digs.
– Diagnostic data of their state of preservation. After over one hundred years exposed to the elements, the funerary complexes of CAC have undergone a process of deterioration which has affected especially the paintings, a detailed description of which is essential to understanding its state of preservation as a whole.

– Study of the causes of deterioration. Apart from the inventory of the state of preservation of the funerary complexes, it was imperative to conduct a prolonged study of the causes of deterioration. For this purpose a team from *Consejo Superior de Investigaciones Científicas* (CSIC) monitored a selection of funerary structures to study the behavior of certain environmental parameters: relative humidity, temperature, exposure to sunlight and concentration of CO_2 for over two years. In the end the factors that triggered the deterioration processes affecting the tombs were isolated and measures taken to try to correct them.
– Geophysical prospecting. Most of the surface that CAC encompasses was the object of archaeological exploration, but the degree to which these explorations were exhaustive is unknown, as is the existence or lack of new underground complexes in areas that were subsequently incorporated into CAC. To arrive at an approximation of CAC's current archaeological potential, geophysical prospecting has been conducted and presumably-intact underground archaeological structures have been detected.
– Research on the visiting public. The modern management of CAC requires the most detailed knowledge possible of the behavior of the public, as well as the load capacity of the site with regard to the number of visitors it can support. All of these aspects have been analyzed.

4. SICAC applications

4.1 *SICAC Desktop*

SICAC Desktop resides on CAC's servers. It was designed to facilitate management of the means to conserve, research, and share information about the archaeological goods existing in CAC. It consists of a database of all archival, planimetric, photographic, bibliographic and archaeological information, with hyperlinks to the digitized archives, and the GIS application. This application was developed in gvSIG, a geographical open source software system that fulfills the requirements for implementing SICAC. SICAC Desktop is organized in three views, differentiated by scale, purpose and content. The first view, called "Alcores," shows the known archaeological sites in the municipality of Carmona. Its function is to provide territorial contextualization of the *Necrópolis Romana de Carmona* and to guarantee protection and preservation of the archaeological sites. In addition to the polygonal layer of the sites, a vector mapping at a scale of 1:10,000, a historic raster mapping; the map of the first series of the Army Topographic Service at a scale of 1:50,000 dated in 1918, the map of the municipality of Carmona of 1923, and the entire series of ortho-photographs available by WMS connection dated in 1956, 1977, 1985, 1999, 2001, 2004, 2007 and 2009 have been added. The principal view, "Necropolis", interconnects all the geographically-based information available at CAC, structured into

a series of layer groups defined by topic. In reverse view order, the topics are: ortho-photography, historic maps, visibility, CSIC, cartography, archaeological structures, legal limits, thematic tombs, and dissemination areas.

The ortho-photography group includes the set of ortho-rectified aerial photos that are available by linking to WMS services. There is also CAC's ortho-photography taken in 2010 at a resolution of 5 cm/pixel. This layer group finalizes with a raster map of the DTM that resulted from the 2010 aerial photo flight. The "old maps" layer group consists of the maps created after the first excavations of the *Necrópolis Romana de Carmona*, digitized and ortho-rectified. Included in the maps are the Bonsor and Fernández López working maps, showing the excavated archaeological structures and identifying numbers assigned to them, as well as the first complete map of the digs, published in the first guide to the site in 1885 (Fig. 6). The map from 1970 made during excavation of the amphitheater is also included. The "visibility" layer group includes three raster maps of the visibility studies analyzed for archaeological research by CAC. The first of the layers shows a cumulative viewshed created by plotting the main entrances to the city from the West. For contrast, the inverse map is provided, a cumulative viewshed analysis from all tomb sites that generally coincide with the previous map, showing the direct relationship between tomb location and visibility. There is also map of the viewshed from the Servilia tomb, the largest at CAC, that demonstrates its connection to the ancient road from Carmona to Seville.

Under the "CSIC" tab is a series of layers derived from the research activities that CSIC has been carrying out since 1991 at CAC to diagnose the causes of deterioration of the *hypogeum* structures. It includes a map of the geological and lithological composition of the rock into which the structures are carved, a polygonal layer that reflects the areas of anthropogenic accumulation of soil, which has a strong influence on the preservation of the *hypogeum* structures, and two other layers derived from the hydro-mechanical analysis of the place: a vector map of the surface water runoff system and another of the sinkhole areas where rainwater accumulates. Several planimetric surveys are included in vector format, both general and partial, which have been carried out at CAC since 1991, last updated in 2010, in the "cartography" group.

The essential layers of the system are under the "archaeological structures" tab (Fig. 7). The first one, called "Access to Tombs," shows the structures that are visible on the surface. The second one, called "Section Tombs," creates an architectural drawing of the underground structures and provides a real map of the spatial distribution of the toms and other archaeological structures over the site. The layer "Tombs," in Shape format is associated with an exhaustive data set. It provides the code and the traditional name of the tomb, the number given to it by its discoverers, its typology and a series of descriptive characteristics such as the number of niches, number of burials, chambers, surface measurement, etc.

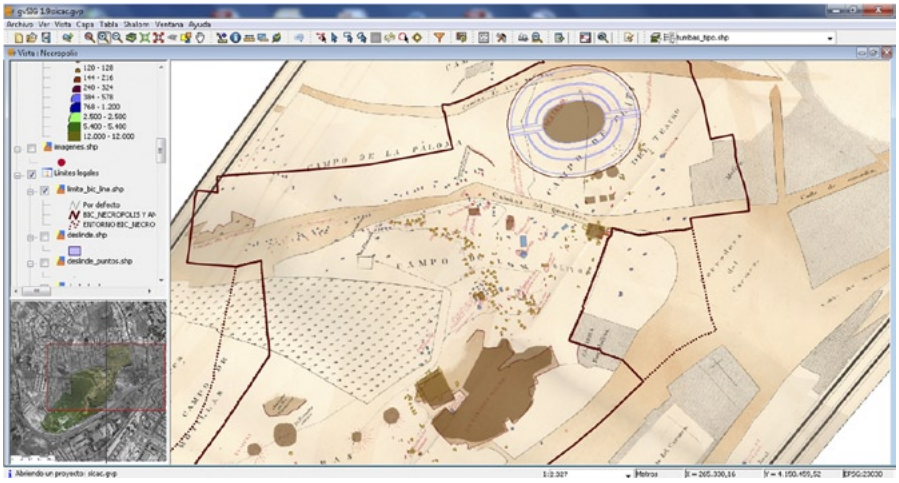

Fig. 6 – SICAC Desktop. "Old maps" layer.

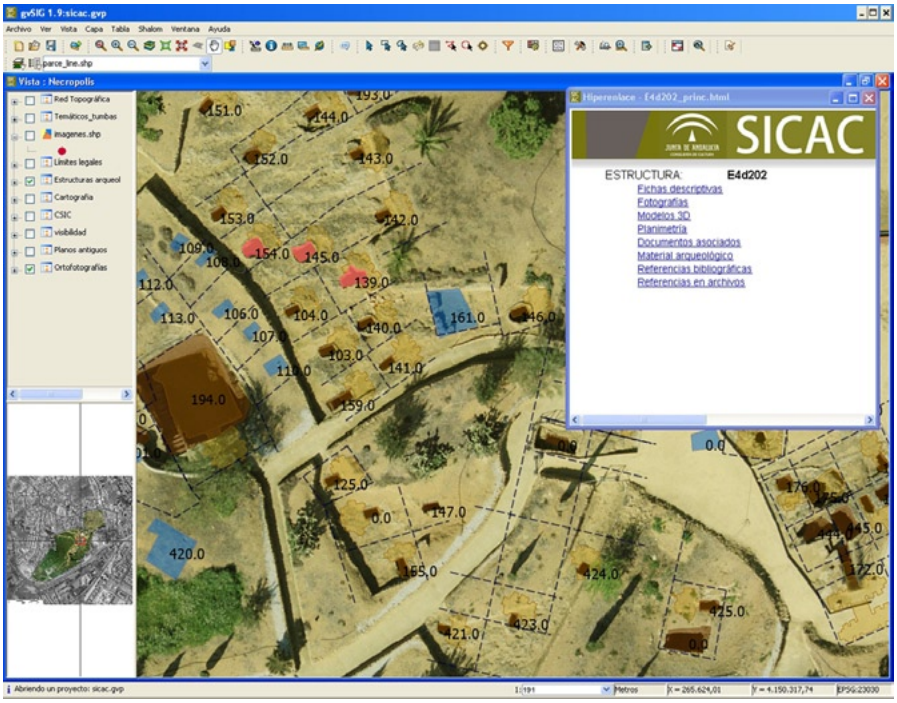

Fig. 7 – SICAC Desktop. Archaeological information.

The hyperlink tool leads to an html file offering the following alternatives to access the data: "Descriptive fact sheets," "Photographs," "3D Models," "Planimetry," "Associated Documents," "Archaeological Material," "Bibliographic References," and "References on File." The link to "Descriptive Fact Sheets" gives access to the description and archaeological analysis file for each tomb site and to the diagnostic fact sheet about its state of preservation. The link "Photographs" leads to the inventory of historical photos from 1885 to 2005 for each structure, or to the digital photos taken from 2005 to the present. "3D Models" leads to the 3D models of each tomb, based on a mesh created from the point cloud resulting from the laser scan of each structure. Three resolutions are available. A high resolution that utilizes 0.2% of the original point cloud; a medium resolution with a mesh based on 0.04% of the original points and a low-resolution option which is used on the SICAC website, using 0.008% of the point cloud. These models are viewable and interactive, using Adobe Reader v. 9 or higher (Fig. 8). Under "Planimetry" are the maps of the tombs that have been published in the historical bibliography and those existing in the CAC archives. The remaining tabs are still under construction and will link to the digitized files of the documents derived from the preservation and research work associated with each tomb. Under way is an inventory of the archaeological material existing in the collections of CAC and in other museums, and its connection, not always possible to define, to each structure. The documents existing in the archives and the bibliographic references are being analyzed in order to link each document and each page to the tomb sites and other archaeological structures of CAC.

In "Archaeological Structures" there is a layer called "Archaeological Information" that encompasses all surface features carved into the rock that could be linked to the funerary structures. It includes a layer that shows the geographic referencing mesh used to denominate each archaeological structure. It is composed of two grids, the larger one with cells sized 100×100 meters, distributed using UTM geographic coordinates and labeled with letters A-G on the X axis and numbers 1-6 on the Y axis. Each cell is subdivided into 10×10 m cells labeled A-J on the X axis and 1-10 on the Y axis. Thus the tombs are identified by a 6-character code in which the first two characters correspond to the letter and number of the larger grid, the second two correspond to the letter and number of the smaller grid, and the two final digits correspond to the numbering of all structures existing in each cell, starting from the North and going clockwise in consecutive order. Other aspects are included in this group, subject to the evolution of archaeological research, that correspond to the restitution hypothesis of the shape of the Roman amphitheater, the distribution of the funerary parcels in the necropolis and of the roads that would run through this *coemeterium*. The group "legal boundaries" comprises the vector layers that delineate the protected area. This is for the purpose of the legislation on historical cultural heritage that is in effect, and the parcels that

Fig. 8 – SICAC Desktop. Guirnalda tomb, 3D model. Longitudinal section.

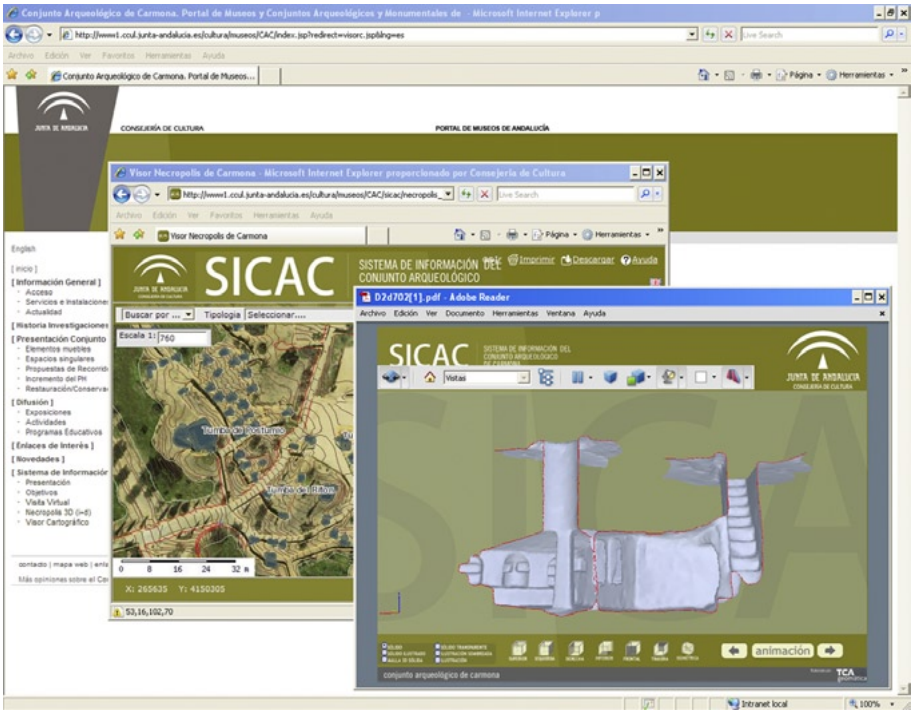

Fig. 9 – SICAC Web. User interface.

are public property. The "thematic maps" give different options, transformed into a shape point format, for visualizing the tomb sites. It is a tool for viewing different thematic maps according to tomb typology, chamber size, number of niches or the estimated measurement of the parcels they occupied. "Information Sharing," the last viewable group, covers the visitable tomb sites and areas of CAC as well as points of interest along the existing itineraries.

The third and last view is exclusively for daily management of CAC and contains information relevant to regular maintenance work. SICAC Desktop has been in operation since September 2010. It receives daily is always subject to daily data updates, implementation of new data layers and the completion of pending projects for linking together the archaeological materials and bibliographic references, not to mention integration of the entire archaeological record system used during excavations done at CAC.

4.2 *SICAC Web*

The web version of SICAC was placed in operation in June 2010 to provide our visitors and external researchers with the 3D survey of all of the tomb sites, geo-referenced on an updated CAC mapping and high-resolution ortho-photography in a GIS environment (Fig. 9). The application is developed in p.mapper, based on MapServer, a platform for publishing spatial data and interactive maps on the web. In vector format, an actualized mapping of CAC is shown, highlighting the importance that orography has in the morphology of the site. In two polygonal layers, the archaeological structures of CAC are shown in a manner analogous to that mentioned under SICAC Desktop. The first of the layers gives access to associated data and also provides a link to visualize a 3D model of the tomb site in low-resolution. As with SICAC Desktop, this file is seen with Acrobat Reader v. 9 or higher. The final touch is a point-layer associated with a 360º panoramic view of specific places in CAC. It is available in two languages, Spanish and English.

The success of the initiative is apparent from the figures we have collected on the number of visitors from countries on all five continents, which leads us to plan for an increase in the functionalities and information offered. This has already been developed for SICAC Desktop and SICAC Mobile.

4.3 *SICAC Mobile*

In 2011 the VirtualPolis project was launched, financed by the *Ministerio de Cultura*, to create applications for providing information at archaeological sites. This project, completed in March 2012 has allowed us to adapt part of the SICAC Web and Desktop data for mobile devices, implementing new content. The objective of this application is to provide contextual information *in situ* with an augmented reality application for smart phones and tablets. The VirtualPolis

project was developed using the Layar application for iOS and Android operating systems. There are four categories for the layers. The first is called "Tombs" and it uses the mobile device's GPS to recognize archaeological structures, bringing up a small fact sheet with the floor plan of the *hypogeum* structure, its code, name and type. The second category, "Ustrinum," is a compilation of the simple funerary structures: the pit, *bustum* or *ustrinum* types that do not have a funerary chamber. The reference codes and types are presented on the mobile devise.

The "3D Tombs" category is the most developed. It is, in principle, especially for the main tomb sites of the sector known as "Las Guirnaldas sector," composed of Cuatro Departamentos, Ustrinum, Guirnaldas, and Tomb 418. Outside of this set, the amphitheater is also included. A 3D icon has been developed such that one can explore the underground environment, with the funerary chamber displayed on the mobile device as a cutaway through the roof. The icon brings up associated data as well as a video of a virtual visit of the tomb site in its present state and a simulation of its original morphology that is so far only available for the Cuatro Departamentos and Guirnaldas tomb sites. Users can also listen to the audio-guide or use the application "Time Machine," which gives a 360º panoramic view toggling from the present state to a simulation of its original state using a sliding bar. Lastly, a 3D viewer of relics has been developed, "Ánfora 3D," displaying relics that correlate to funerary structures or with the CAC museum. It is an interactive viewer that makes use of the touch-screen on the mobile device. The last category, "Photographs," provides access to a selection of 60 photographs taken from 1885 to 1930, geo-positioned at the coordinates and the angle from which there were taken so that users can compare the current state of the site with the old photographs.

In conclusion, a three dimensional model of the Roman amphitheater based on a rigorous process of re-creation from the information gathered in the most recent studies and digs that have taken place at the monument (Fig. 10). The 3D icons and the panoramas for the Time Machine application were developed from this model.

5. Future perspectives for SICAC

SICAC is a fully operative reality in its three environments (Fig. 11)[1] but it is not a finished product; it is only just beginning. There is still much information to analyze and to relate to the archaeological structures in SICAC

[1] Technological aspects of SICAC. SICAC Desktop: Software: gvSIG Desktop ver. 1.9.; Minimum necessary computer: Pentium IV 2300 Ghz/2GB RAM, 500 GB HD.; OS: Windows XP/Vista/Seven/8, Linux, Mac OSX 10.6.8. SICAC Web: Framework p.mapper; SIG server: MapServer; Computer for installation: Pentium IV 2300 Ghz/8GB RAM, 1 TB HD 7200 rpm; Database: MySQL ver. 5.4.10; OS: Red Hat. SICAC Mobile: Computer for installation: Pentium IV 2300 Ghz/8GB RAM, 1 TB HD 7200 rpm; Database: MySQL ver. 5.4.10; OS: Windows Server 2003; PHP Language, ver. 5.3.8. Javascript language supported by Framework jQuery 1.7.1, jQuery Mobile 1.0 y Openlayers 2.2.

Fig. 10 – SICAC Mobile. Amphitheatre re-creation using an augmented reality application.

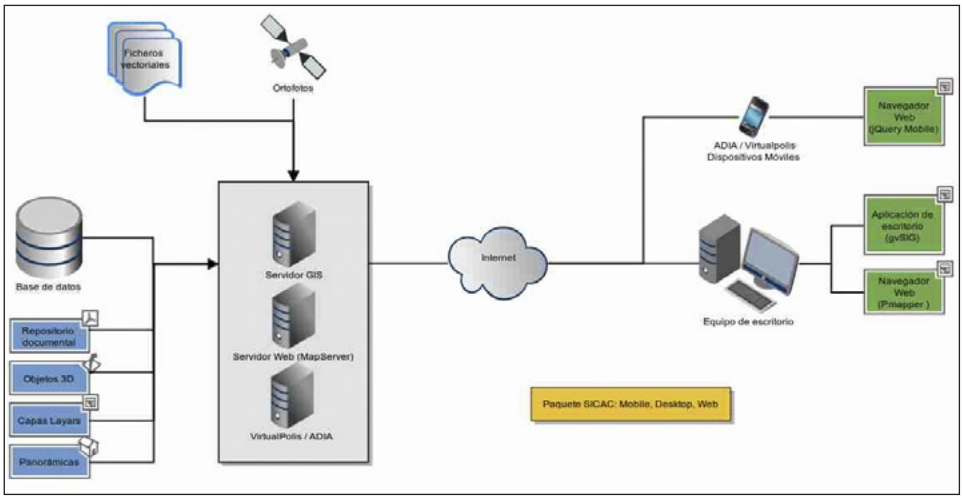

Fig. 11 – SICAC. Logical scheme.

Desktop. The next step is a small GIS project for each funerary structure. On the surface of the mesh we intend to apply several thematic maps, such as a photorealistic texture based on photographic reporting of each structure, a map that shows its current state of preservation and pathologies, an archaeological interpretation map that shows the different stratification units that are distinguishable on the structure and then to associate written and graphic information with each of these elements. The content will continue to grow with daily management.

The contents of SICAC Web must grow and develop. The collection of historical photography geo-positioned at the coordinates where they were taken together with current photos, geo-referenced historical maps, videos and audio guides, the "Time Machine" or "Ánfora 3D" application, all of this will enrich the content, making SICAC Web more attractive to offsite visitors or for people planning their visit to CAC. Ever more immersive ways of experiencing the information are in the nascent stages of design, starting with devices for onsite viewing of 3D videos of the funerary complexes around the Guirnaldas tomb. We have great expectations for the future.

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ABSTRACT

The Roman necropolis and amphitheater of Carmona (Seville, Spain) were excavated and opened to the public at the end of the Nineteenth century. Because of this long continuity, the Carmona Archaeological Ensemble boasts a special trait: a broad archaeological documentary archive. Efficient management of this store of information that is updated and added to on a daily basis required a computer application that could gather, integrate, conserve and facilitate the use of this volume of data from different sources. At the same time, it was considered necessary for researchers to have online access to the core substance of the information. Our information system for CAC was developed over the course of five years and is called SICAC. All of the graphic and alphanumerical data is organized in the same environment, thereby guaranteeing their integration, availability, quality and accessibility. SICAC has three platforms: desktop, online and mobile.