An online archaeological Atlas: the webGIS for the monuments of Hierapolis in Phrygia

Introduction

The recent publication of the *Atlas of Hierapolis in Phrygia* (D'Andria *et al*. 2008) was accompanied by the creation of a webGIS platform (http://antares.ibam.cnr.it/atlante-hierapolis), developed by the ANcient Topography, Archaeology and REmote Sensing Laboratory (ANTARES Lab) run by the Institute for Archaeological and Monumental Heritage of the Italian National Research Council (IBAM-CNR). The software used for the online version, whose purpose is to complement and enhance the book version, was developed in collaboration with the SIRTER s.r.l. company of Taranto[1] (Fig. 1). The book provides a summary of fifty years of research by the Italian Archaeological Mission; their findings are presented in 53 plates on a scale of 1:1,000, each accompanied by information describing the main monuments and archaeological areas.

The volume is the result of studies by researchers from a number of disciplines, particularly experts in geomatics from the Faculty of Architecture of the Politecnico of Turin and archaeologists and experts in ancient topography from the University of the Salento (Lecce) and IBAM-CNR. The large-scale representation provided by the atlas thus includes detailed archaeological digital maps and information from the topographical and archaeological surveys of the urban area and nearby necropolises. The *Atlas* presents a highly heterogeneous collection of archaeological data, drawn from excavations conducted by the Italian Archaeological Mission, systematic archaeological surveys of the city and surrounding territory, multi-temporal aerial and satellite images, and geophysical surveys (magnetometric prospection and Ground Penetrating Radar).

The online version of the *Atlas of Hierapolis*, currently only available in Italian, is accessible from both the IBAM-CNR website (www.ibam.cnr.it) and the section of the Italian Archaeological Mission website dedicated to Hierapolis (www.misart.it). The online version is based on the data published in the hardcopy version, but has been designed so that it may be updated and enriched with new data as they emerge from the continuing research. It can also be expanded geographically (for example to include the archaeological evidence from the territory surrounding the city), and can also include content of different kinds (such as video). The web platform provides users with an introduction to the city and its monuments and was created for the specific purposes of communication and information-

[1] The online *Atlas of Hierapolis* was created under the scientific coordination of G. Scardozzi with editorial assistance from L. Castrianni, I. Ditaranto and G. Di Giacomo. The latter also took care of the graphics and the development of the software and the database.

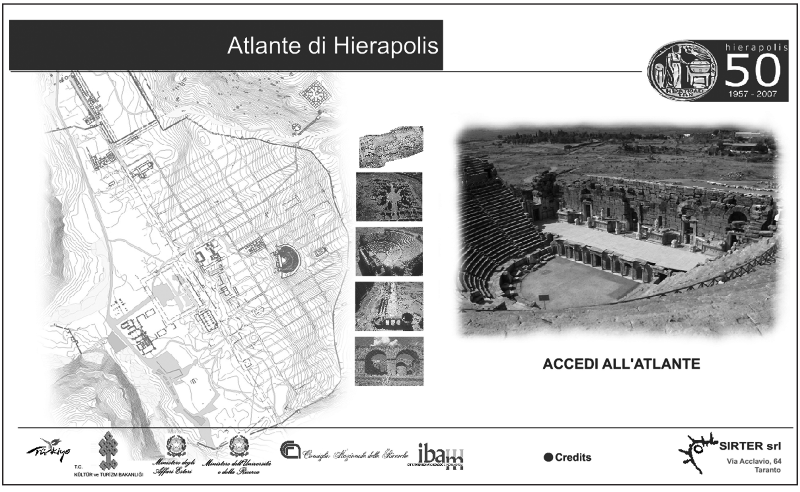

Fig. 1 - The *Atlas of Hierapolis* home page. The 50 years logo of the Italian Archaeological Mission at Hierapolis of Phrygia gives access to the brochure published in 2007.

sharing with a broader group of users than the specialised readership of the book. It is presented as a rapid and effective means of "visiting" the ancient city that may be used by scholars, students and whoever may be interested in finding out about Hierapolis.

Accessing the online *Atlas of Hierapolis*, it is possible to view the cartography and the historical, archaeological and topographical data associated with it. Navigation is based on the archaeological map drawn by the architects of the Politecnico of Turin (the version available online is the raster image on a scale of 1:2,500) and on a pan-sharpened satellite image (in real colours) acquired by QuickBird-2 on 25-3-2005. The latter, which provides a fairly up-to-date and detailed overhead view (with a resolution on the ground of about 70 cm), was processed by the ANTARES Lab. The image in question was purchased from DigitalGlobe, the owners of the QuickBird-2 satellite, via the company Telespazio S.p.a.; in future it may be replaced with a more recent image or accompanied by other layers made up of further satellite images acquired in different years and/or by different satellites.

Methods and technologies

Web-based GIS applications (webGIS) were created for the specific purpose of presenting geographical information in a simpler and more accessible way than standard GIS systems to expert and non-expert users alike, using the resources of the internet. In this context, it is necessary first and foremost to structure the data being distributed, establishing *a priori* the hierarchies that link the various cartographical layers and the dynamic search and interrogation functions of the system. This first phase of development helps the system designer to decide whether it is better, for example, to use a geo-database, which generates vectorial data at the request of the user, or a shapefile linked to metadata. Using the former will be more difficult in the implementation phase, but much faster in terms of rendering the data. Indeed, the greatest limitation of the internet is not being able to transfer data from the server to the remote client rapidly. This limitation however can be overcome by optimising resources and choosing those technologies which, after the feasibility study, are found to be the most suitable for achieving the desired result.

Regarding the online *Atlas*, it was decided to use a server with state-of-the-art hardware and excellent performance in terms of data-processing speed. This server, running Windows Server 2003 RS2 to simplify machine management, is hooked up to the CNR-IBAM network via a static IP address, accessible via the internet. The operating system is the only non-open-source resource installed on the machine: indeed, the web services are not managed by Internet Information Services (IIS), which have been deliberately deactivated, but by Apache HTTP Server. There are two distinct Apache Server services on the machine, one that takes care of the management of the ANTARES Lab website (using port 80), and one that manages only cartographical services (using port 8080). With this configuration, when a user writes the web address of the online *Atlas*, the server is able to establish firstly whether they are trying to access the webGIS resources, and secondly to re-route the request to the cartographic engine automatically, freeing resources and thus speeding up the simple navigation of the ANTARES Lab website.

For the cartographic engine, it was decided to use UMN Mapserver, developed by the *University of Minnesota* (UMN) in cooperation with the *Minnesota Department of Natural Resources* (MNDNR) and NASA, issued free under GPL (*General Public License*). This is currently one of the most stable and fastest Open Source cartographic engines available. Like all cartographic engines, when suitably configured it is able to render cartographic data (in raster or vector format) in association with metadata, extracting them from a geodatabase (MySQL or PostgreSQL with PostGIS) or from a shapefile. Conceptually, the technology on which the system is based is very simple: the remote user, working with a normal internet browser such as Internet Explorer, Firefox, etc., sends a request to the cartographic server to visualise one or more layers of the webGIS, possibly in association with the metadata of the individual entities. This request is actually a very small text file, containing the requested data and the coordinates of the area of interest. Once the server receives the request, it processes it, generates an image which is the result of the query, and sends it to the remote user. At the same time it prepares itself to provide, again on request, the metadata available for all the entities present in the visualised area. The image generated in this way is thus an excerpt of the layer being interrogated: therefore the quantity of data that must be sent from the server to the client is much smaller, with a considerable saving in terms of waiting time. Using this system, the visitor does not need to download any software or plug-ins to access the cartographic resources: this means that the webGIS is easily accessible from any remote workstation, simply by typing the address of the online *Atlas*.

The final user is thus provided with cartographic data in raster and vector format, satellite images (panchromatic and multispectral) and historic and archaeological data. The organisation in layers enables navigation around the 2005 QuickBird-2 satellite image (suitably “lightened” for web exploration) and – should the user require – around the archaeological cartography superimposed on that image. The layer with the archaeological information is linked to a database that allows the user to make simple or complex queries, integrating spatial and temporal data. This makes for a highly dynamic approach to knowledge of the city, though it should be stressed that in this phase of development of the system, the queries are pre-set, and are selected from two drop-down menus.

Content organization and management

In consideration of the dynamic and interactive nature of the webGIS platform compared to the book version of the *Atlas*, some sections have been slimmed down, combined or even eliminated, in order to enable a more rapid and immediate consultation. Thus for example the introductory articles focusing on the methods applied in the creation of the digital cartography and the archaeological map of Hierapolis have been excluded. In contrast, attention has been focused on the corpus of records for the individual monuments and the archaeological areas, which constitute the fundamental core of the *Atlas* and provide a detailed description of the city and the necropolises.

With respect to the hardcopy version however, the general layout of the webGIS has been substantially modified. While in the former the records are organised in accordance with the division into plates, in the online version they are directly linked to their topographical position in the general cartography of the city, so as to enable an even more immediate approach and a more dynamic navigation of Hierapolis. In accordance with these criteria, the records for the individual monuments were extrapolated from their relative plates, while some homogeneous archaeological areas described in more than one plate were combined in a single record.

For example, concerning the Byzantine city walls, a general record for the whole circuit was drawn up, as well as other more specific records for the excavated and better-conserved gates (the North and South Byzantine Gates, St. Philip’s Gate, the Gate above the Theatre, the South-West Gate). For the urban layout, a general record was created for the city as a whole (subdivided into northern, central and southern areas) and specific records were extrapolated for the monumental area to the South of the Sanctuary of Apollo and the vaulted structure to the South of the Great Baths. Regarding the road network outside the city, records were created for the areas to the North and South of the city, while the South Gate was given a record of its own. From the North Necropolis a record was extrapolated for the Solitary Tomb, which is located separately from the others to the North-East of the city, on the summit of the hill occupied by the North Theatre. In total, in the online version (as in the DVD enclosed with the hardcopy version, see below) there are 70 records, compared to more than 100 in the book. These two types of documentation are linked by the bibliography of the records in the online *Atlas*

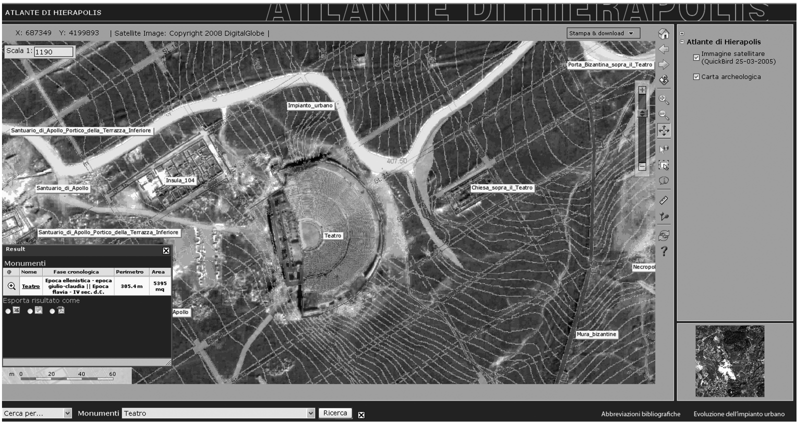

Fig. 2 – Example of a query concerning the Theatre. The search can be performed by moving the cursor over the map and/or satellite image or within the database.

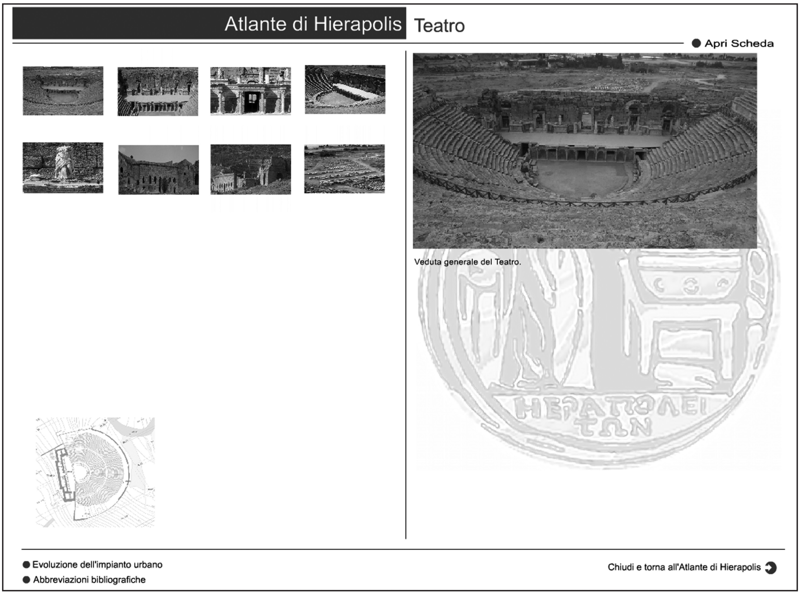

Fig. 3 – The page of the Theatre in the online *Atlas of Hierapolis*.

of Hierapolis, which contains references to the plate or plates in the book which contain the archaeological evidence described.

In the online platform, each monument or archaeological complex in Hierapolis is connected, via a link that appears when an archaeological find is selected, to a Flash object containing images with explanatory captions (visualised in a preview

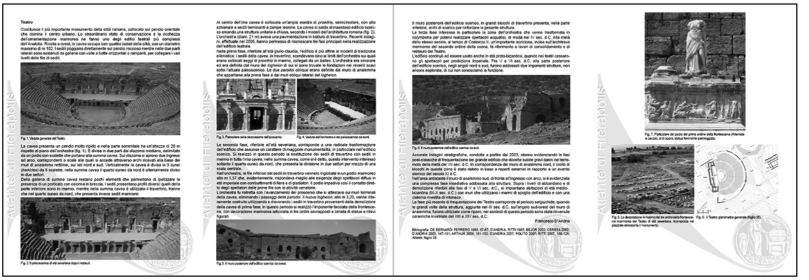

Fig. 4 – Screen shots of the descriptive record of the Theatre.

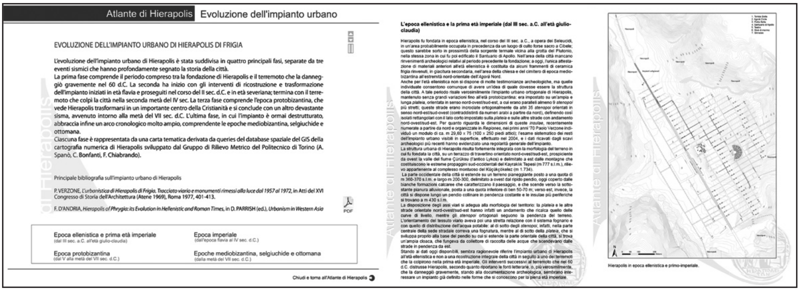

Fig. 5 – The "Evolution of the urban layout page" of the online *Atlas of Hierapolis* and an example of the schedule on the Hellenistic period and the Early Imperial age.

that can be enlarged on request), and to a record in .pdf format. The latter contains the text and images of the book (enriched in some cases with further photographs) and the section of the archaeological cartography in which the monument in question appears (Figs. 2-4).

There are two ways to retrieve the records of the monuments: the first entails navigating the map or the satellite image and selecting the monuments or the archaeological areas about which more knowledge is required; the second involves searching for the monument by name or historic period, tracing the development of the city through each of its four main phases: "Hellenistic epoch and Early Imperial age", "Flavian age to the 4th century AD", "Proto-Byzantine epoch (5th-mid 7th century AD)", "Mid-Byzantine, Seleucid and Ottoman epochs". With the second type of search, which takes place by consulting a list of the entities or the four chronological phases (Fig. 2), it is possible to retrieve all the monuments or archaeological complexes belonging to a given historic period individually, and visualise them together on the archaeological map of the city, generating a complete map of a particular phase, with the option of accessing the relative images and descriptive records.

If the user wishes to visualise all the monuments of an individual chronological phase, in addition to the queries he can also use the link "*Evolution of the urban layout*" to access a page that contains a record for each of the four main phases of Hierapolis. Each of these records includes a specific map on a scale of about

1:5000 showing all the monuments pertaining to that period, thus documenting the diachronic development of the city. This section of the online *Atlas* is a summary of the long article which appears in the book dedicated to the evolution of the urban layout (Fig. 5). The links "*Evolution of the urban layout*" and "*Bibliographical abbreviations*" are always available, both on the page with the interface for navigating the city and on the web pages dedicated to the individual monuments or archaeological areas.

As well as providing easier and more immediate access to the graphic and photographic documentation, at the same time the online version of the *Atlas of Hierapolis* offers an overview of the historic development and topographical location of the individual monuments and archaeological areas of the city. This is a dynamic structure which, unlike the basically static arrangement of the book, enables the final users to interact with the archaeological map of the city and to play an active part in the knowledge process, as they study the history, archaeology and topography of the site.

The DVD of the *Atlas of Hierapolis*

The DVD sold with the hardcopy version mirrors the structure of the online *Atlas of Hierapolis*, enhancing the book's illustrative power. It provides all the cartography, satellite images and digital terrain models in high resolution raster format. Its content, also created with ActionScript technology, is arranged in four sections: "*Atlas of the city and the necropolises*", focusing on the description of the monuments and the archaeological areas, with the same records in .pdf format as the online *Atlas*; "*Cartography*", with the archaeological maps on a scale of 1:10000 and 1:5000 and all the plates of the *Atlas* on a scale of 1:1000, again in .pdf format; "*Satellite images*", with a selection of images, both panchromatic and pan-sharpened with real and false colours, found in the book; "*Three-dimensional terrain models*", with a selection of digital terrain models obtained with various methods, draped with satellite images and the archaeological map of Hierapolis. In the section entitled "*Atlas of the city and the necropolises*", as in the online *Atlas*, the user can navigate the archaeological map and make queries concerning the monuments, but the search procedure is different; rather than by typing the name and interrogating a database, the user chooses from a list linked directly to the map. In the DVD, because of the different technology used for its development, it is not possible to interrogate the system using space-time queries, which in the online version enable the generation of maps of particular phases.

Conclusions

The online *Atlas of Hierapolis* represents the completion and the natural extension of the data gathered in the book *Atlas of Hierapolis in Phrygia* (D'Andria *et al.* 2008). It forms part of a publishing project implemented using various means of communication. It is a powerful and dynamic tool, which naturally lends itself to regular updating and periodic implementation of new systems for the consultation and distribution of data.

Acknowledgements

The *Atlas of Hierapolis* online, the archaeological surveys and research on the ancient topography of Hierapolis and its territory have been made possible thanks to the constant support of Prof. Francesco D'Andria, Director of the Italian Archaeological Mission and of CNR-IBAM, and responsible scientist of the web platform. Archaeological cartography has been realized by Antonia Teresa Spanò (coordinator), Cristina Bonfanti and Filiberto Chiabrando from the Faculty of Architecture of the Politecnico of Turin. The schedules contained in the *Atlas* are of the coordinators of the areas of excavation and restoration in Hierapolis: P. Arthur, M.P. Caggia, L. Campagna, F. D'Andria, R. D'Andria, G. D'Elia, T. Ismaelli, P. Mighetto, D. Peirano, I. Romeo, D. Ronchetta, M.P. Rossignani, G. Scardozzi, G. Semeraro, A.Z. Ruggiu.

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Photogrammetry, GIS and Remote Sensing techniques applied to the Roman Villa of Aiano-Torraccia di Chiusi (Siena, Italy)

Foreword

The site of the villa at Aiano-Torraccia di Chiusi[1] is located in the municipal district of San Gimignano (Siena, Italy) in the valley of the torrent Foci. In spite of the fact that the site was discovered some time ago, it had never been studied before the summer of 2005, when the Université catholique de Louvain (UCL, Belgium) decided to start a project in order to systematically explore the site over several years.

This decision was taken because of the interesting archeological finds from the site, and in particular because it was considered necessary to re-examine – possibly on the basis of new data – the numerous questions, on the population, the economy, the rural environment, etc. of the Valdelsa area (the valley of the river Elsa) in the Roman period. The period considered is quite wide, as it extends from the first phases of Romanization, to Late Antiquity and the Early Middle Ages (1st century B.C.-8th century A.D.).

Available archaeological data

During the first four excavation campaigns, 1000 m^2 were investigated out of the one hectare which is thought to represent the surface of the villa.

Up to now the excavations have brought to light an important part of the villa, probably an area of *otium* (living room), characterized by a wide triangular room, with corners in the shape of circular exedras. The discovery of this area, of which ca. 100 m^2 have been excavated so far, revealed the residential function of the place and the high degree of cultural and economic development of its inhabitants. Moreover, the study of the different archeological findings showed that, in the area already excavated, there has been a succession of various building methods and life styles, which transformed the aspect, the plan and the functions of the villa (Fig. 1).

Photogrammetry

For this work, concerning collection of images and data setting, we used a consumer digital camera (Nikon Coolpix P3) and a total topographic station with reflecting prism (Topcon GTS-702). For the photogrammetric elaboration and the classification of images we employed the elaboration suite LEICA ERDAS

[1] http://www.villaromaine-torracciadichiusi.be/.

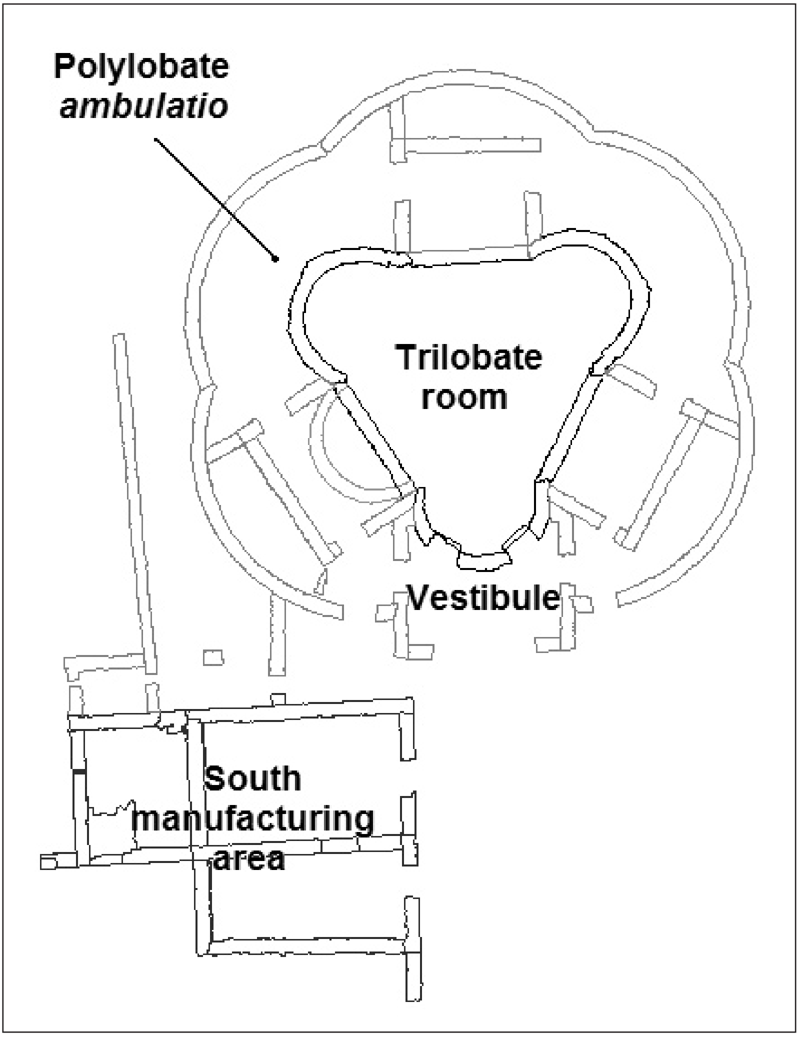

Fig. 1 – Plan of the Roman villa at the end of the fourth excavation campaign (1000 m²), summer 2008.

IMAGINE 9.1 with the extension LEICA PHOTOGRAMMETRY SUITE; for digitization and for the construction of a vector database we used the software ARCGIS 9.2.

The operative sequence of photogrammetric research consists of some fundamental passages. Firstly, the right choice is important of both the frames of what will become the stereoscopic block, and the internal orientation of the camera. In this case the use of non-metric cameras allows the inclusion of only some parameters related to optical geometry (focal length and pixel size). Moreover the projection of points on the ground must be specified and this represents the most essential point of the work[2]. In this case the stereographic projection was taken as the proper one. Secondly, we tried to establish a connection between the frame and a suitable ground reference system. To do this, the Ground Control Points (GCP), selected with the total station, were collimated by inserting coordinates x, y and z. In this way the points are kept in a correct spatial relationship, allowing thus the creation of the so-called stereo pair.

Further, it is also useful to insert check points in order to reduce the RMSE[3]. A further improvement is given by the inclusion of a large number of tie points. These points are collimated like GCP, but the information on the 3 coordinates is not available. They establish an objective relationship above the corresponding points on the 2 photos. The inclusion of tie points follows the entry of other automatic tie points, but the result does not improve and, in one of the considered cases (small ditch), we identified a sort of clustering. In different areas the automatic algorithms positioned the points close to other ones already manually collimated. Once included the control points and the manual and automatic tie points, we calculated the triangulation which established the mathematical relationship between the images building the block file and the orientation information already included. The two cases of study are presented below.

The ditch

DTM and orthophoto

The aerial triangulation process of the small ditch was obtained by the RMSE of 6.6 units, but it must be stressed that the rotation angles of the base of the frame collection, ω (roll), φ (pitching) e κ (drift), is limited if we consider the initial condition of release of photos.

We then passed to the creation of the Digital Terrain Model (DTM) of the area taken into consideration. The mainly automatic extraction process could be carried out without any problem. A medium-high quality DTM was obtained and, during the elaboration, a raster file was also created, showing the different chromatism which displays the quality of the produced DTM.

Whatever method we chose, we can see that the less accurate areas of extraction and creation of DTM are those close to the edges of the small ditch. In fact, the lack of ground point and the almost vertical abutments of the structure do not allow an effective documentation, i.e. it is as if part of a photo were missing. The stretching of pixels constituting the orthophoto, visible in these points, is the con-

[2] The term stereographic projection identifies – in geometry and cartography – the projection of points on the surface of a sphere from a point N of the sphere (often called the North pole of the sphere) over a plan – usually the equatorial plan – or on the tangent plan of a point called S, South pole (to antipodal N).

[3] *Root mean squared error* between the real position of the object and the one collimated on the photo.

sequence of shootings in areas with many *breaklines* and it produces an irregular ground surface. The next step was the correction of DTM points in places where quarrying was more difficult. It is quite obvious that areas, in which there is not a good interpretation by the algorithm of automatic quarrying, are difficult to understand also for the operator. As the next step, a new punctual feature was created by using the Stereo Analyst of Leica Erdas LPS. We tried to put in, through the stereoscopic view, as many points as possible in areas of minor detail. After that, the monographs of the points were included among the parameters necessary to the extraction of a new DTM. However, at an immediate autoptical examination, the results did not seem to improve the situation. Therefore we moved on from the results of DTM and the orthophoto of the small ditch, to the video-digitalizing by means of the Stereo Analyst module.

Before drawing, we estimated the characteristics of the area to be tested, and discovered that not only the earth matrix but also a quantity of bricks and travertine blocks had been widely used in the building of the villa. Indeed, the abutments of the small ditch consist of bricks vertically placed and leaning against the store walls, which belong to places close to the settlements. The conclusion is that it is correct to underline the building materials because they are essential. Therefore two linear features called “bricks” were created.

The digitalizing process evidenced some difficulties in the photogrammetrical elaboration in the particular situation of the small ditch. The tested stereo-pair was affected by problems, already noticed in the creation of block file, and these problems influenced the next stages of the process. The photographic collection carried out with a non-metric and non-calibrated camera do not have a high precision. The use of a “bar” built and improved during the plotting allowed a reduction of the rotation angle, but not the total elimination of errors. Further, the ground collimated points for this stereo-pair were of a lower number and the reduced “height of flight”[4] and the particularly uneven ground of an area with vertical and sub-vertical face, but irregular in many points, would require an overlap with very high coverage of 80% or more. Regrettably the highest possible percentage of overlap we can have is between 50% and 60%, because of the uncertain situation and the short period of work. This value is acceptable[5] but not sufficient to allow a complete superimposition of the details of the photos. In some cases, and even in the centre of the stereo-pair close to most of the uneven area, there are elements, which are not perfectly visible in both photos. With proper digitalizing, the central part of the photo should be evidenced, where the document structure is placed and where the most interesting archaeological characteristics are. Here, more than

[4] The process for frame collecting used here can be joined with the one of aerial photogrammetry even on land, i.e. from top to bottom, without control by the methods employed.

[5] In theory, the covering of “standard” aerial photos would be 60%. In rough areas a higher overlap, of around 80%, is recommended to keep the details of the photographed area. In these cases, a pattern of flight which follows the relief and the valley and avoids to intercept perpendiculars is adopted, so as not to create stereoscopies where “some” of the elements included in one of the two frames are not present in the other.

anywhere else, there are some visible elements of bricks and travertine, free of the earth which covers them, and we tried to draw them by underlining the exposed rim. The linear drawing so digitalized, can also be seen as tridimensional thanks to the visualization software ArcScene of ArcGIS.

The geodatabase

The first aim of the video digitalizing was to create a vector database from which to obtain a detailed plan of this excavation area. After creating the feature and vectorizing the outline of the relevant elements, the final file is saved as shape, i.e. in one of the formats of ArcGIS. The initial files are presented as closed polygons. The correct creation of a database required the passage to polygons. The procedure followed was to create a Personal Geodatabase with ArcCatalog, including dataset in which were inserted the linear shape and a new punctual shape created *ad hoc*. The latter is used to "validate" the polygons obtained from the polylines through opportune steps carried out with the software GIS.

In the geodatabase the special domains should be edited. In this case we chose a domain called "class" of coded values by type to which two values are attributed: 1 for the bricks and 2 for the travertine. The polygonal shape obtained is related to the domain of geodatabase through the "fields" of the database. In fact it includes a new field, called "classification", which is the first created as reference domain (Figs. 2 and 3).

The polygons are then assigned to the correct class they belong to, by using ArcMap, and by asking the vector file to show the wording "bricks" or "travertine" among the information linked to the file.

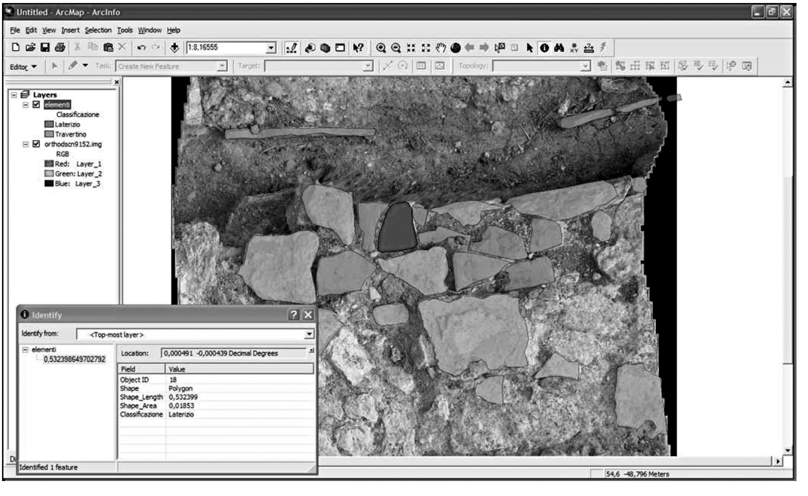

Fig. 2 – Screenshot of the geodatabase.

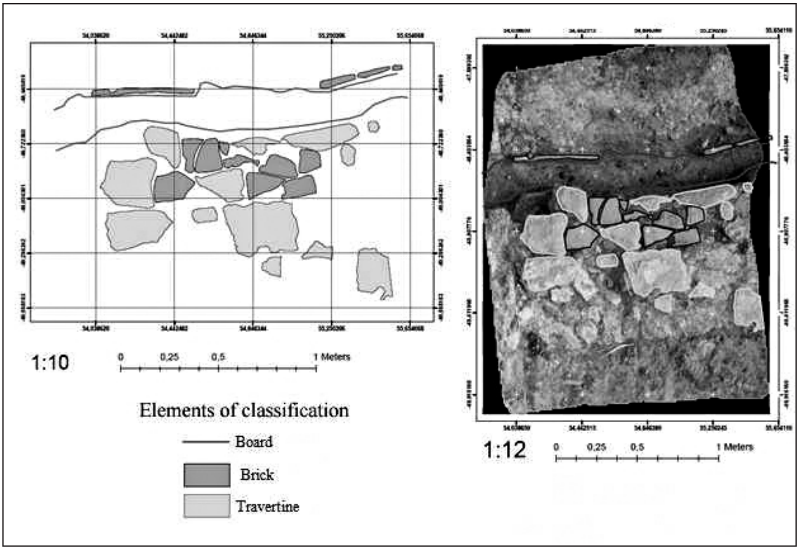

Fig. 3 – Aiano-Torraccia di Chiusi: classification of building materials.

Surface analysis

After creating the DTM, the orthophoto and the database, we tried to carry out some analysis of real surface of major dimensions. It has to be underlined that it is also possible to apply these analyses to objects of smaller size, for example the small ditch discussed above. Through the module 3D Analyst of ArcGIS we are able to obtain some thematic images of the slope and the depth at different points of the tested structure. The data are prepared in this way: the elevation image, represented by a raster colour-scale painting, is replaced from the DTM to the surface TIN (Triangular Irregular Network) composed by irregular triangles, linked to each other, in order to produce a DTM.

The created TIN and the orthophoto related to the small ditch are imported in ArcScene. We planned a symbology with 32 classes from the file property. We used a chromatic scale with light-brown gradation, except for the classes with a lower elevation. For these we used a colour which immediately shows the lower area. We gave transparency to the orthophoto converted in grey scale (so as not to be disturbed by natural colours) and to the TIN, in order to point out the characteristics of the superimposed layer.

Subsequently, to show the slope of the structure faces we used the slope function. This function allows to point out the inclination percentage in the different areas of DTM. With ArcScene we created an image by which it is possible to see the inclination of the shoulder of the small ditch with the chromatic differences. To avoid all images being coloured again, we prefer to delete the values under a certain percentage (20%) as we do not consider them to be indicative. This visualization is useful to understand the problems given by the photogrammetry in the area of the abutment of the small ditch. The problems are mentioned above, i.e. the stretching of the pixels are located in the areas with a major inclination.

The kiln

After including the control points and the manual and automatic tie points we were able to calculate the aerial triangulation, establishing the mathematical relations between the images which build the block file and the orientation information already included.

Operating the aerial triangulation leads to the creation of a summary containing the principal data on errors (RMSE), the aim of the GCP. The calculated RMSE is equal to 1,2473 unit; the error is acceptable, if we consider the difficulty of catching images through the bar for "aerial photos".

Stereo Analyst, DTM and orthophoto

Once finished the orientation either internal or external, we tested the perfect superimposition of the images belonging to the block file inside the Stereo Analyst. The extremely low error and the optimal photo catching of the block file lead to an excellent superimposition and to an almost perfect stereoscopic vision of the images, except for a small defect of parallax in the direction of the y coordinate. The creation of DTM and of the orthophoto allowed to obtain a tridimensional model of the surface of the kiln and of the stratigraphic units closer to it.

These procedures are useful in the different stages of study and interpretation of the archaeological evidence, after the conclusion of the excavations. They also assume a high documentary value, because the excavation is unrepeatable and unique, but also, at the same time, it is destructive. In this way there is the possibility to have the DTM helping the work of archaeologists in post-excavation stages.

Remote sensing: classification techniques of images and post-classification elaboration

One of the fundamental aims of remote sensing techniques is to produce thematic maps of the tested surface through the images from artificial satellites. In order to create maps quickly, it is necessary to make a ground classification or, as in the case of the kiln[6], a catalogue, according to categories corresponding to a selected standard of research.

There are two methods of classification: supervised and unsupervised. Through a supervised classification the operator can find out the spectral signatures[7] of

[6] In this case, the analysis is done on frames with only 3 bands of visible (RGB). Therefore the processing is simplified if compared to multispectral satellite images.

[7] The signature or spectral response is defined as the "fingerprint" of any object surrounding us. It is a chart that informs us about the amount of energy reflected from a body, according to various wavelengths of the electromagnetic radiation incident.

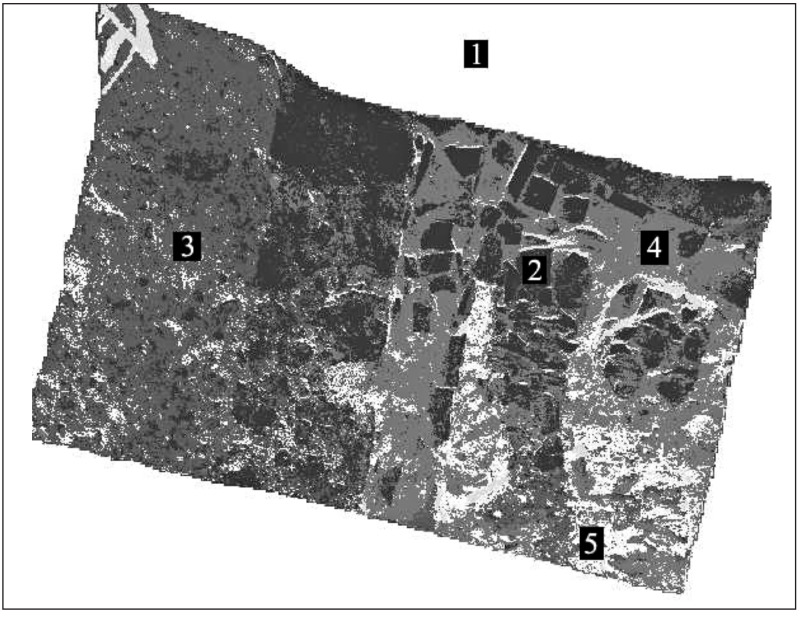

Fig. 4 – Unsupervised classification with predefined classes, based on stratigraphic units.

well-known categories[8]. Secondly particular types of algorithms correlate each pixel of the image to any Training Set[9] of reference, matching or similar to our spectral signature.

The second type of classification, i.e. the unsupervised, does not require prior information on the classes that it will create. Such classification analyses on the image pixels are divided in the more common spectral groups present in the data. This process is called clustering. Only subsequently the operator identifies the clusters and attributes each of them to recognizable classes.

Unsupervised classification

The unsupervised classification does not require the use of external directions in order to attribute the pixels to the different classes. This type of classification subdivides the classes on the basis of the numeric information present in the data. This process is called clustering and it is based on the statistic grouping of image pixels through a standard of mutual contiguity so that the groups of pixels (or cluster) result internally united and mutually disjointed. Various algorithms can be employed; however the operator can decide how many groups the algorithm

[8] Define, in this way, Signature Training Set reference.

[9] Areas of example. That is, groups of pixels that can be considered representative of a class.

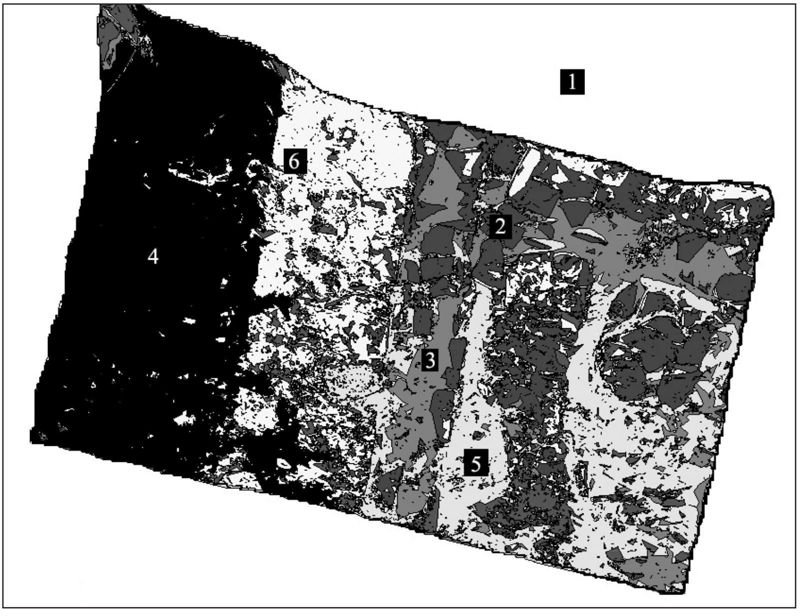

Fig. 5 – Supervised classification, using the algorithm of Maximum Likelihood, which perfectly discriminate the 6 classes and allow the "raster to vector'' conversion for acquisition in GIS software.

should define. Only after this the operator admits the cluster calculated on the basis of the algorithm to the identified classes.

Isodata is the algorithm of clustering used by software Erdas Imagine. It is a complex heuristic algorithm, based on the principle of assigning each pixel to a cluster with the close centre (minimum spectral distance) and of recalculating the positions of the centres after the elaboration. These are:

– The maximum number of clusters admitted. They point at the greatest number of the classes that can be obtained.
– The threshold of convergence[10]. The threshold value avoids an algorithm to enter a non-ending cycle.
– The maximum number of interactions. It does not allow the algorithm to continue for a long time or to enter a non-ending cycle.

The number of clusters is not defined during the iteration but it can change, for example when a cluster with a small number of pixels is deleted. Those very close to each other are united and the ones which are too far from each other are divided. However, at the end of repetitions the number of the classes fixed *a priori* must

[10] It is the highest percentage of pixels whose assignment to a cluster cannot change from an iteration to another.

be restored. The numbers of identified classes for the classification of the kiln are five: 1) Not classified; 2) Tile and bricks; 3) Stratigraphic unit 2191; 4) Clay-based ceramics; 5) Embankment.

This subdivision is decided first, on the basis of the knowledge of stratigraphic units tested and represented in the frame[11] (Fig. 4).

Supervised classification

This procedure gives the operator complete control of all the classification process. There are two techniques of classification:

a) Techniques of parametrical classification. This method is based on a statistical procedure, such as the mean or the matrix of covariance. The algorithms of parametric classification used by the software are the following:

– Minimum Distance: calculates the mean for every band of DN (Digital Number) of pixels belonging to the different signatures. Each pixel will be assigned to the class, the middle point of which is closer (by the Euclidean distance) to the analyzed pixel.

– Mahalanobis Distance: the probability of allotment of one pixel to one class depends not only on the value of its Euclidean distance from the centre of the class but also on the direction.

– Maximum Likelihood: for the classification of each pixel, it will calculate the probability of belonging (i.e. the “similarity”) to each defined class by the signature. Therefore the pixel will be assigned to the class with greater similarity.

b) Techniques of non-parametric classification. A non-parametric classifier can use a set of signatures, either parametric or non-parametric, and assigns a pixel to each class, by using the rules of geometry.

In order to classify the pixels, it is necessary to also use parametric classification techniques, so that each pixel will be assigned to the class with a higher likelihood[12]. Through this classification method it has been possible to create a reliable group of signatures, useful for a correct classification of the images.

Once located the representative examples of each class, we go on with the digitalizing of polygons on the training sites and to the definition of the spectral signature.

Among the two techniques employed, the parametric method was the better one which classified the image, in particular when using the algorithm of Maximum Likelihood (Fig. 5). For this reason the values of DN have a normal or Gaussian distribution. This means that the frequency of values will be around the mean of each category and diminish with increasing distance. This algorithm is the one that has the greatest precision. Unlike the other algorithms, this last created a careful classification, even if not completely exact. Indeed, the so-called “salt and

[11] The orthophoto obtained from photogrammetry is the image used for the implementation of the classifications.

[12] Another possibility is to leave them unclassified.

pepper effect” stays rather high even after carrying out techniques of post-classification elaboration, such as smoothing.

As Fig. 5 shows, the algorithm could perfectly discriminate the 6 classes identified with the polygons in the training set: 1) Not classified; 2) Tile and bricks; 3) Mortar and clay; 4) Stratigraphic unit 2191; 5) Clay-based Ceramics; 6) Travertine blocks.

Post-classification elaborations: raster to vector conversion

The final product of classification is represented by a data raster of thematic type. An attribute, circumscribing its own class of pertinence, is associated to each pixel through its own list of belonging. However, the raw data obtained by the classification often needs a series of improvements to develop the informative context. These procedures, called post-classification elaborations, are the smoothing and the conversion raster to vector.

After the smoothing, we change the original file, in a raster format, into a new file of vector type. This process happens automatically, with the creation of polygons which have pixels of some characteristics. The vector file allows a better visualization of the classified image, and allows easier and faster editing by the operator.

Through this function it is possible to export a vector editable file (Fig. 5) inside ArcGIS, and once inserted inside the excavation GIS it becomes a functional unit of the same GIS.

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