SESSIONS

Prospection and Remote Sensing – Advanced Methods for Archaeology

The Roman town of *Ammaia* (Portugal):

From total survey to 3D reconstruction

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Abstract: Simultaneous with on-going archaeological excavations of the Roman town site of *Ammaia* in South-Central Portugal, a group of researchers acting within the EC funded project “Radiography of the Past (Radio-Past)”, have during the past two years, achieved a full coverage geophysical survey of the intra-mural part and large tracts of the extra-mural areas of this abandoned ancient city in *Lusitania*. Using a wide array of instruments, for prospections with GPR, earth resistance and magnetometers, this approach allowed an in depth analysis of an abandoned Roman centre, linking the excellent survey data with stratigraphic information, obtained via earlier excavations and via focused ground truthing operations, including small trenching and augering. Together with data from remote sensing and fine DGPS surveys this now allows to study the urbanism of a very systematically and *ex novo* built Romano-Lusitanian town. Part of the field project also leads to a tentative reconstruction of many aspects of the urban pattern and structures, providing a unique high resolution survey-based approach to visualising ancient cities. This paper presents aspects of integrated methodology of survey, high resolution mapping results and discusses the process of visualisation of the site in Roman times.

Keywords: non-destructive survey, Roman towns, Lusitania, 3D Visualisation, Reconstruction.

The project *Ammaia*: the framework

As recent research is more and more proving (CAMPANA and PIRO 2009; CORSI and VERMEULEN 2010; VERMEULEN et al. 2012; MILLETT and JOHNSON forthcoming), the integrated approach, merging traditional instruments of research like surface artefacts collection, aerial photography interpretation, topographical survey and excavations, with up-to-date techniques of geophysical and geomorphological survey, is disclosing new perspectives in our knowledge of complex (still buried) archaeological sites. In most cases, this synergy allows the production of a 2D map of the site, where excavated evidence can be paralleled with buried structures detected via the interpretation of the geophysical survey and/or aerial photography coverage. Three-dimensional perspective can be achieved with the integration of Ground Penetrating Radar (GPR) data, corings, test pits, ground-truthing excavations and production of Digital Terrain Models (DTMs), while the overlap with the processing of the finds collected on the surface can enlighten some aspects of chronological occupation and evolution of the site. These peculiar aspects of studying and visualizing deserted archaeological sites are the core objectives of an EU funded project, the

People/Marie Curie IAPP project short-named Radio-Past[1]. The researchers of the project, composed by staff of four academic institutions (the University of Évora in Portugal, Ghent University in Belgium, the University of Ljubljana in Slovenia and the British School at Rome, a UK institution) and three SMEs (the companies 7Reasons Media Agency from Austria, Past2Present from The Netherlands and Eastern Atlas from Germany), integrated with post-doc recruited researchers, join their resources and very different skills to tackle each possible aspect connected with archaeological survey, mainly on (abandoned) urban sites.
The project Radio-Past seeks mainly pathways to integration of different methodologies in the wide and by now spectacularly developed field of non-destructive survey systems and technologies applied to archaeology, but also pursues the valorisation of the results by innovative ways of visualisation and the development of strategies for efficient management of the sites. Furthermore, the project also concurrently targets the development of effective scientific systems for the dissemination of survey results. In particular, the combination of high-resolution fieldwork with computer-based means of mapping and data visualisation, should allow virtual reconstructions of a buried town or large settlement within a relatively short space of time, as opposed to the more traditional excavation-centred approach that could take generations before a broader view of the site becomes available.
The operational strategies and the integration of different approaches is tested in several “open laboratories”, selected archaeological sites spread over the Mediterranean and continental Europe, where different teams of researchers gather during survey campaigns. The most important “open-lab” of the project Radio-Past is the archaeological park of the Roman town of *Ammaia*, in Portugal.
Here many research and fieldwork activities are carried out since the mid Nineties, under the scientific direction of the Universities of Évora and Coimbra first, and under the sole direction of the University of Évora since 2007. The latter is also piloting other projects in partnership with the Portuguese National Research Fund (FCT) and several universities (Cassino, Ghent and Lisbon: see CORSI 2012: 159–163), where *Ammaia* is the main target of scientific research.
The site, being a deserted Roman town, now almost completely free from modern constructions but with the unfortunate exception of a state road cutting through the archaeological site, very limitedly agriculturally exploited (mainly olive trees), has been declared “Monument of National Interest” in 1949. Now, the management of the site and of the in-site small museum is attributed to the Fundação Cidade the *Ammaia*, which also owns the lands on which most of the estimated intramural surface of the Roman town extended.
Ammaia was a mid-size town located in central Lusitania (Fig. 1), possibly founded in Augustan age (end of the first century b.C.–beginning of the first century AD), which in the time of the emperor Claudius (first half of the first century AD) was elevated to the status of civitas, and only later became a municipum (terminus ante quem: emperor Lucius Verus, 161–169 AD). Its ruins (Fig. 2) are located in the Freguesia of São Salvador de Aramenha, in the municipality of Marvão, in the heart of the Natural Park of the Serra de São Mamede, a mountainous area of east-central Portugal, extending into Spanish territory.

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[1] ‘Radiography of the past, integrated non-destructive approaches to understand and valorise complex archaeological sites’, starting date 1 April 2009, duration 48 months: see: www.radiopast.eu, VAN ROODE et al. 2012. The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 230679, under the action Marie Curie – People IAPP.

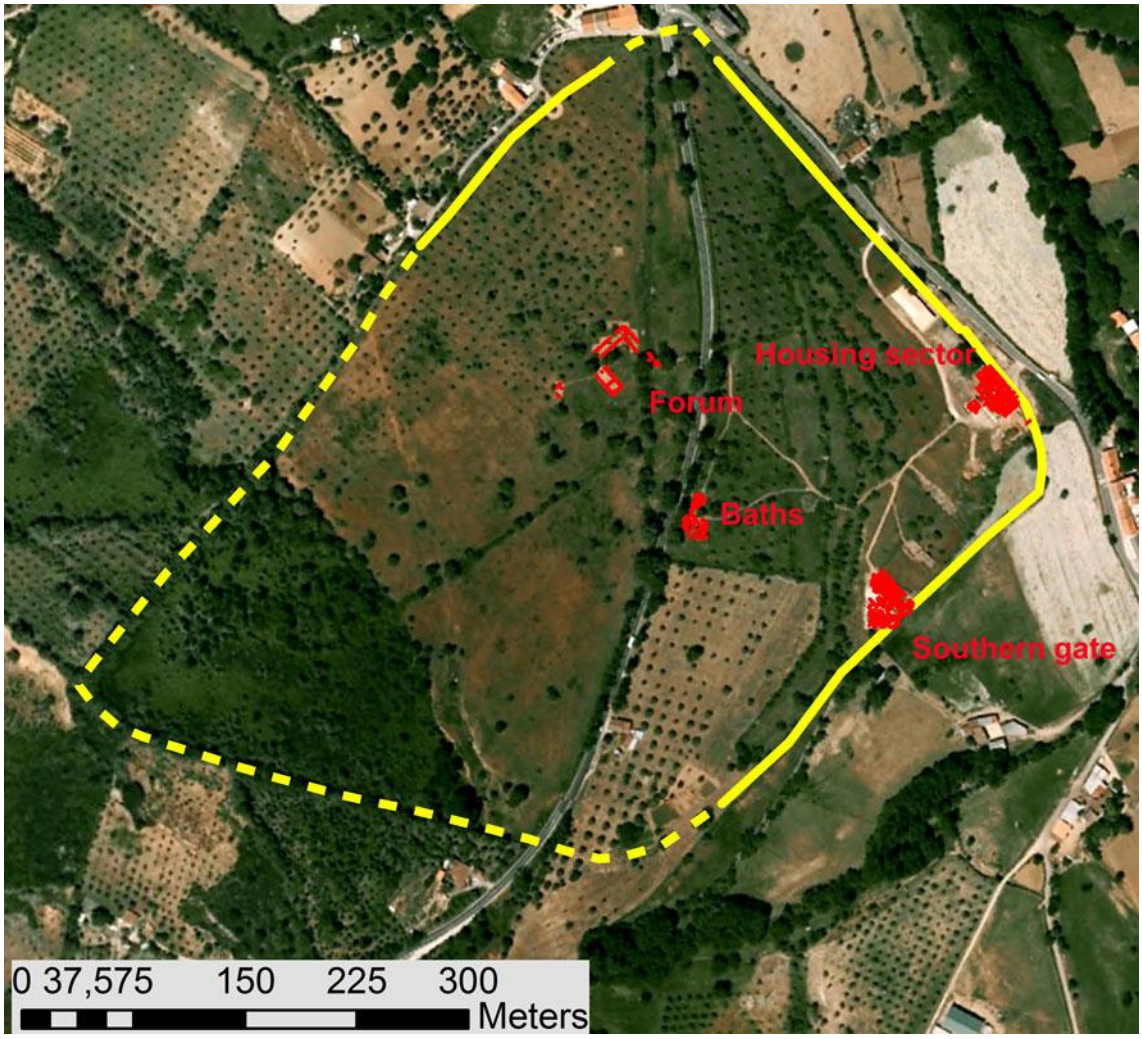

Fig. 1 – *Ammaia* (S. Salvador de Aramenha, Marvão - Portugal): view from the air of the site with the indication of the main excavation areas (Copyright: Radio-Past).

The datasets

Until the beginning of the twenty-first century, archaeological research in *Ammaia* has been limited to traditional excavations, concentrated on areas where ruins were still visible above ground (see Fig. 1), as is the case in the area of the Southern gate (Porta Sul: Fig. 3, n. 3); the Forum area (Fig. 3, n. 5), where the concrete nucleus of the main temple’s podium is still visible and where excavation trenches brought to light segments of a *cryptoporticus;* the main bath complex of the town (Fig. 3, n. 4). Excavations have also been carried out in zones where some restoration work has been conducted, such as in the area around the building that houses the archaeological museum, the 17th-century farm called Quinta do Deão (Fig. 3, n. 1), or where facilities for the archaeological park were planned, such as the visitors car park in front of the museum (Fig. 3, 6). Stratigraphical excavations have been resumed for certain areas in recent years: in the thermal complex (campaigns 2008, 2009, 2011: CORSI and VERMEULEN forthcoming) and in the Forum area with focused excavations in the porticos area (campaign 2010), and the opening of a big trench in front of the temple mainly meant as “ground-truthing” operation for the high-resolution geophysical survey

performed in the Forum area (see further; campaigns 2010–2011: VERMEULEN, CORSI and DE DAPPER 2012).

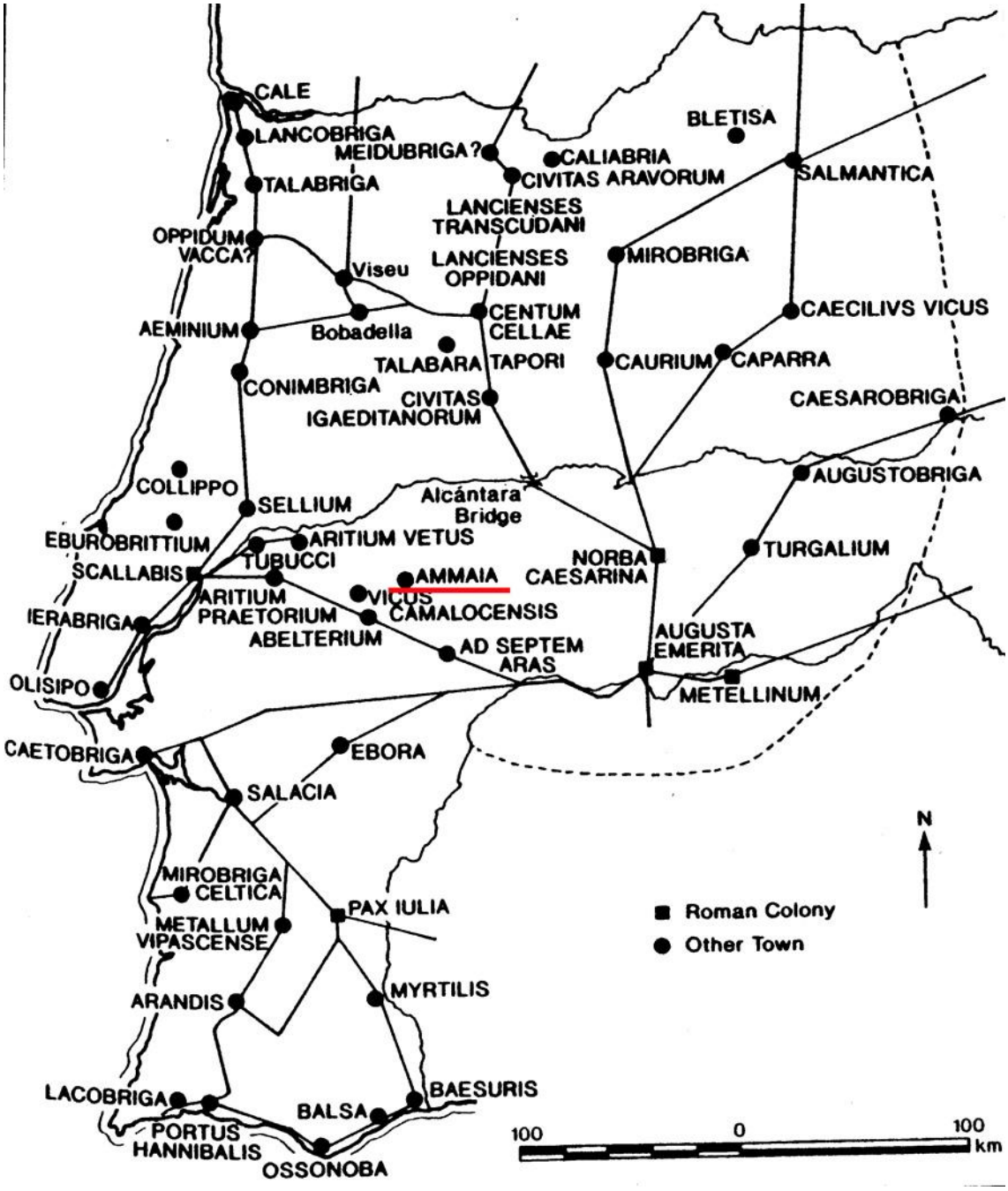

Fig. 2 – Map of the Iberian peninsula with the indication of the delimitation of the *provinciae* and location of the most important Roman towns (After: Edmonson 1990).

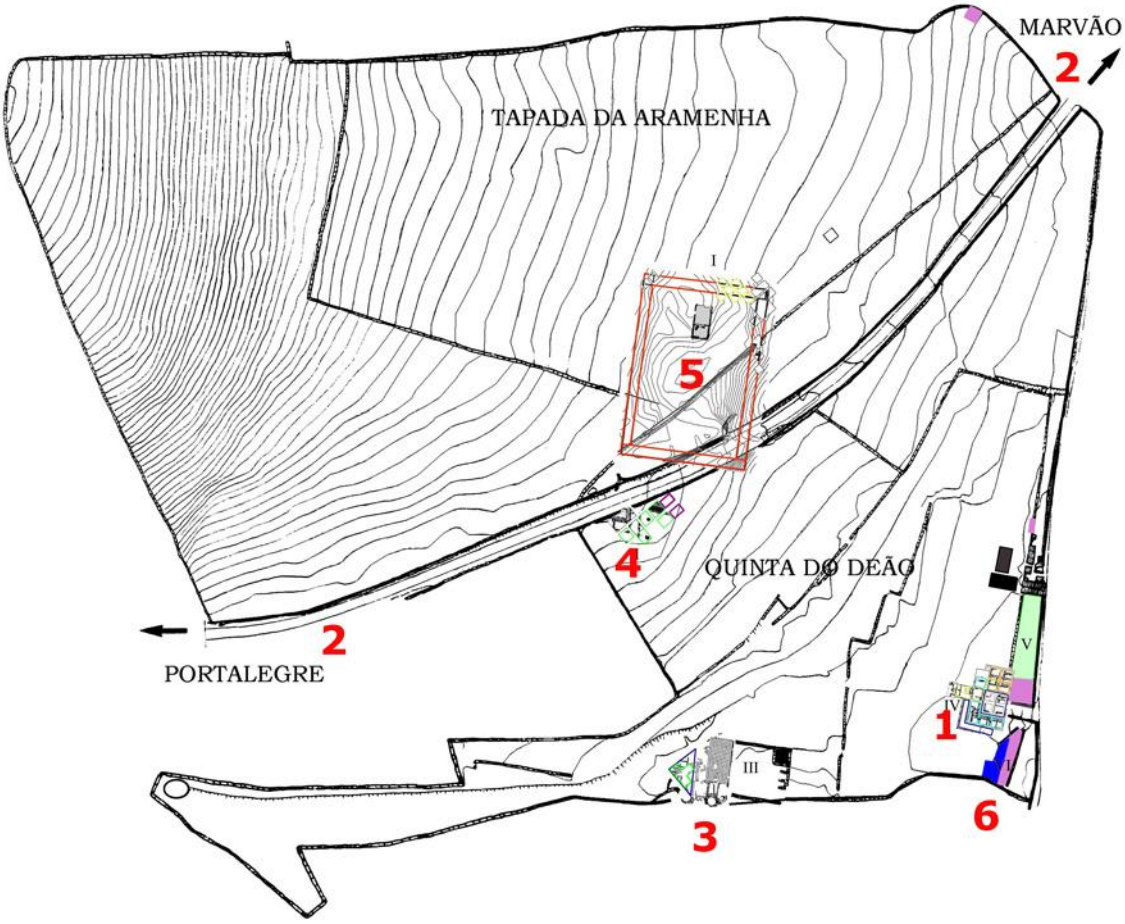

Fig. 3 – São Salvador the Arameñha (Marvão). Delimitation of the area owned by the *Fundação Cidade de Ammaia*, including most of the intramural surface of the Roman town of *Ammaia*. Numbers indicate the location of: 1) the on-site museum hosted into the building Quinta do Deão, 2) the modern road connecting Marvão to Portalegre, 3) the excavated area of Porta Sul, 4) the excavated area of the Thermal bath, 5) the partially excavated area of the Forum, 6) the excavated part of the town wall. Elaboration: C. Corsi, on the base of the cadastral map (copyright: *Fundação Cidade de Ammaia*).

Starting in 2001 a geoarchaeological survey was undertaken by a joined team of archaeologists and geomorphologists from the universities of Ghent and Cassino, with the most important results of the discovery of a long segment of one of the aqueducts of the town and a first proposal for the location of the town walls of Ammaia (Fig. 2) based on surface remains, excavated evidence, and morphological observations (VERMEULEN et al. 2005; CORSI and VERMEULEN 2009). The proposed enclosed urban area, of c. 20 hectares, is situated on lightly sloping terrain near water resources and lies between two narrow palaeo-valleys connected perpendicularly with the River Sever. In this proposal, the walled zone extended to include the small hilltop of Malhadais, probably incorporated for strategic purposes, even if it is our belief that this uphill area was nonetheless never occupied.

As anticipated, the site of Ammaia was chosen by the Radio-Past project as test site for the integration of a wide set of approaches and multidisciplinary survey techniques. We will focus here on the geophysical survey, carried out with different methods and by different teams from 2008 until the autumn of 2011. At the present state of research we can present the results of a full intra-mural magnetometry survey (with the exclusion of the steep slope) for a total extent of 18 hectares (AAPS Southampton and Paul Johnson for the

Radio-Past project); a GPR high-resolution survey for the central area of the town and along the national road N359 (Lieven Verdonck, Ugent, Radio-Past), a high-resolution magnetometry and RES survey of the Forum area (Jeroen Verhaegge, Ugent), a RES survey of a selected area (Paul Johnson, Uevora, Radio-Past), an extensive magnetometry survey of the extramural area (Eastern Atlas, Radio-Past).

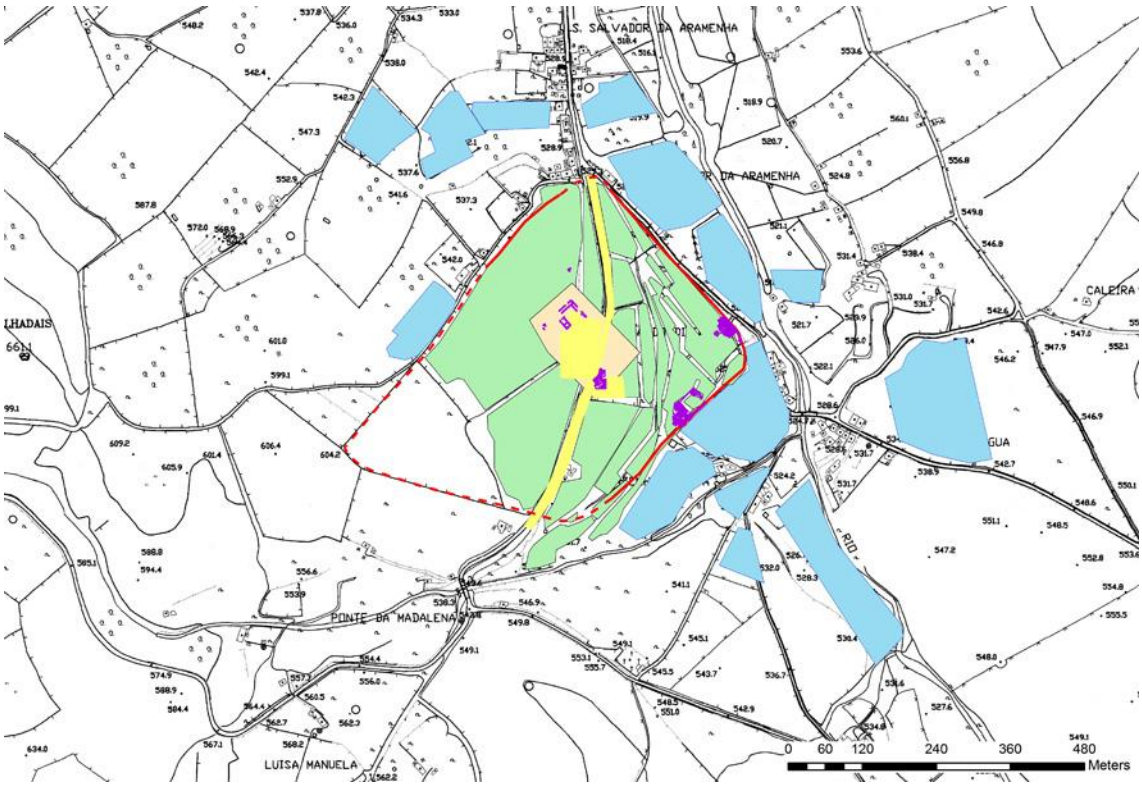

Fig. 4 – *Ammaia*: Area investigated with georadar (yellow, 2008–2010: L. Verdonck), with magnetometry survey (grey, 2009: University of Southampton and J. Verhaegge) and with magnetometry (green, 2010–2011: P. Johnson; blue: Eastern Atlas) on the base of the estimated intramural surface. The presence of the modern road connecting Portalegre to Marvão and archaeological evidence (in red) are also indicated (Elaboration: C. Corsi).

The data interpretation

These datasets have offered invaluable information for many different aspects of the Roman town. The collection and integration of digital data at *Ammaia* aims mainly to assemble and interrelate fragmented data into a more informative whole, so as to increase their interpretive value. For the implementation of these aims a number of digital tools are being employed. Since most of the datasets consist of spatially referenced information the use of Geographical Information Systems (GIS) has been an integral part of data management. Data integration in a GIS significantly facilitates the interpretation of geospatial information, either by simply enabling the combined visualization and interrelation of different datasets, or via the use of spatial analysis and statistics. Several specialists are engaged at the moment in making the best profit of the data integration and in trying to visualize the townscape in its natural environment.

(C. C.)

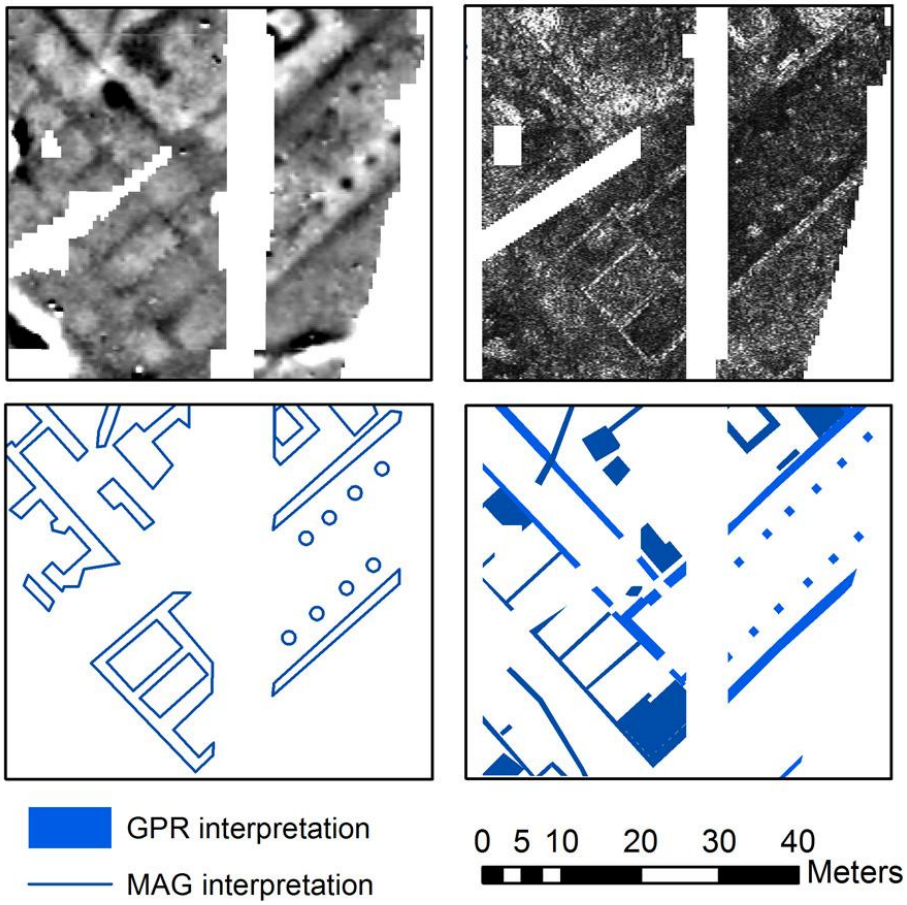

Fig. 5 – Upper left: greyscale image of the gradiometer survey results from the area of the “block XV” SE of the Forum (survey P. S. Johnson) compared with the greyscale image of the GPR survey of the same area (upper right, survey L. Verdonck).
Lower left: vectorised interpretation of the gradiometer survey from the area of the “block XV” SE of the Forum (survey P. S. Johnson) compared with the vectorized interpretation of the GPR survey of the same area (lower right, survey l. Verdonck) (Elaboration: E. Paliou).

The digital reconstruction

The visualisation of the geophysical results is approached by referencing the existing data with better preserved sites of the region and comparing similar structures and dimensions, aiming to preserve architectural local features and details of decoration.

Fig. 6 – Left: View of roman *Ammaia*, Right: The Forum Temple (© 7reasons).

Reconstruction of the visible Remains

Visualisation of "Porta Sul", the South Gate of Ammaia

Fig. 7 – Panorama of the visible remains of the southern city gate "Porta Sul" (© 7reasons).

In a first step the visible monuments of the "Porta Sul" (south city gate) were taken to sketch out some ideas of reconstruction in order to gather experience with existing data and their interpretation. Within this work, different information sources were assembled to create the possible reconstruction.
At first it seemed to be an easy task but then it showed problematic to interpret a valuable height for walls and roofing. The former arch of the Southern Gate was removed in the nineteenth century to be integrated in the city walls of the nearby town of Castello de Vide, but was later dismantled, thus a photo of that time was the only indication of the gates height, while the remaining basement gave exact measurements of its width, suggesting a rather decorative purpose of the "Porta" and the city walls (rather than a fortification purpose).
A certain height was added to support architraves and decorative elements above and around the gate, whereas the dimension of the surrounding building could be defined by the visible remains.

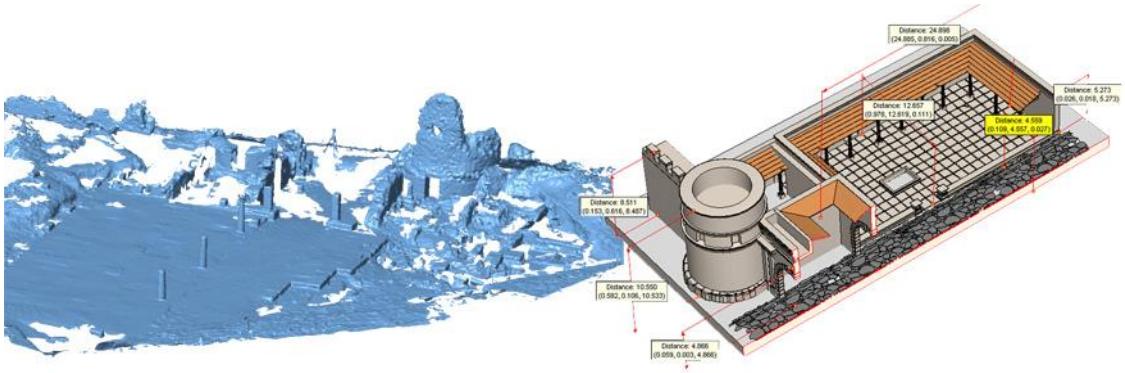

Fig. 8 – 3d Laserscan of the southern gate and a suggestion for its reconstruction (© 7reasons).

From the measures of these proportions we adapted other heights like the city wall and the towers, whereas the reconstruction of the latter is still undergoing intense discussions concerning the proportional fitting of the whole ensemble. The open spaces, to both sides behind the west side of the gates, are laid out with massive (approx. 1x1m) squared granite blocks forming a rectangular shaped square of approx. 23x12 m on each side, leaving us with a total open space of nearly 50x23 m (divided by a street of approx. 4 m width). It is

certain that a place of this size must have had a practical function. The exact usage is still unclear, but it is assumed that a possible market (macellum) connected to the north of the square might have existed here. Together with clearly visible, round marks (holes of approx. 7 cm, in regular interval, 3 m from the surrounding walls) a porticus could be proposed. Although there is no indication if these holes where used for posts, pillars or columns, their placements show that some shelter structure like tends or roofing could be expected. Some regular granite blocks are displayed along the border between the square and the street; they could be interpreted as plinths and they could have been laid down to divide the street from the square in order to keep dirt and water off the square. Together with the visible remains of a threshold on the north-eastern side of the square, and the trace of a basement of approx. 2x3 m (a statue?) various 3D layouts of the “Porta Sul” were made and discussed.

Fig. 9 – Left: Marks of heavy structures. Right: Holes in regular distance (© 7reasons).

The results showed that a first supposed colonnade along the street would have failed to support the architectural conception of the square, since the street width is too narrow to obtain the wanted optical effect, thus disturbing the appearance of the gatehouse, and it was therefore redrawn. In order to visualise the usage of a shelter surrounding the outer walls of the square, we placed a *porticus* according to the measures of the visible (post) holes, but we have to admit that also a much lighter structure, like a tent, held by wooden or iron posts could have been used.

The city wall and its towers are still standing up to 2,5 m and the remains give a good indication of dimension and thickness of these structures. The city walls, in the region of the gate, where approx. 2 m thick and were made in *opus caementicium,* faced with *opus incertu.* However, they, showed no signs of a stone socket, whereas the two towers did. The walls of the towers are approx. 1 m thick and it can be presumed that their height did not reach more that 10 m. Careful and, regular laid out openings in the tower and gate walls, of

aprox. 0,20x0,20 m, could indicate the usage of wooden posts, for construction purposes, but they could also have been used later to support different floor levels with wooden traverses.
While the present state of the 3d Model is quite acceptable, we hope to get more ideas for areas of the towers and the city wall through more comparable material and ongoing discussions. Since the complete reconstruction of *Ammaia* is the main aim of the project we will focus on the more prominent buildings and structures like the Forum, the Baths and the street-layout that surrounded them and we will certainly also refine the proposal on the base of the on-coming information and experiences, which then again can be integrated into an updated version of the “Porta Sul”.

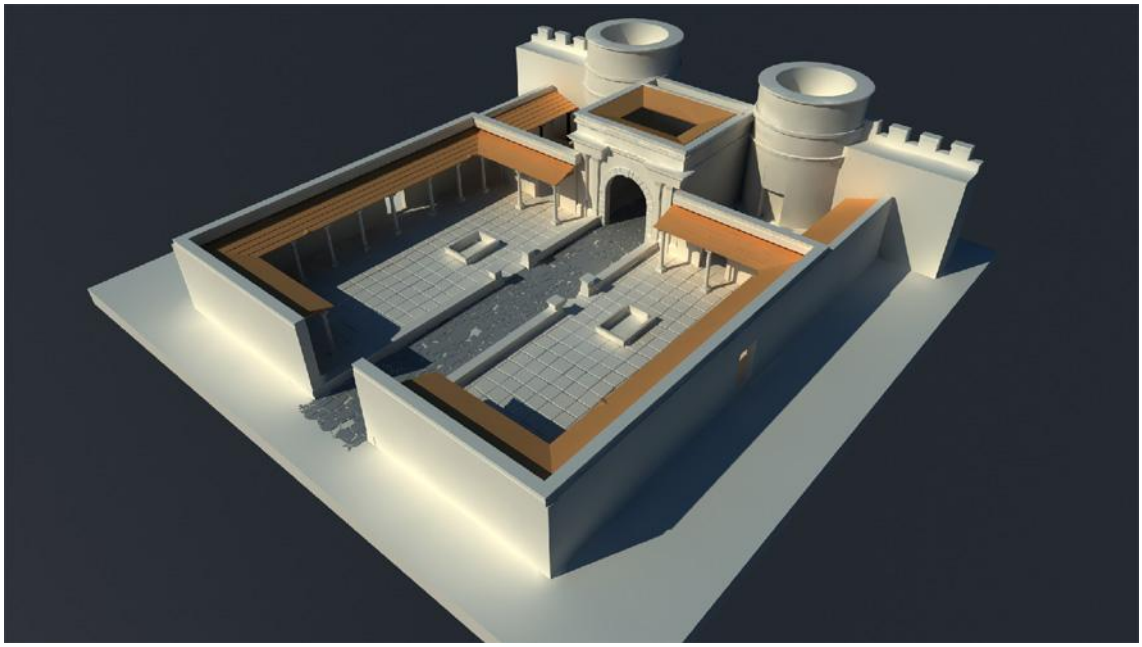

Fig. 10 – Reconstruction of the southern gate (© 7reasons).

Visualisation of the Forum

The Forum of *Ammaia* was partly excavated in the 1994–1998 campaigns, when “Wheeler’s excavation squares” of 10x10 m were opened in the NE corner of the porticoes surrounding the Forum square. As these investigations did not apply archaeological stratigraphy and did not provide enough data for the chronological and typological definition of the complex, new stratigraphical excavations were undertaken during the summers 2010 (*porticus* area and the “esplanade” in front of the Temple) and 2011 (only the Temple area). To get a “wider picture” of the whole complex also various geophysical techniques have been applied (2008–2011) to help to understand the complete structure and plan of the building. The proposed dimensions of the complex measured approx. 65x88 m.
Data retrieved with excavations and comparative research with other better know examples from *Lusitania* were used to reconstruct the buildings heights. The excellent results of the geophysical prospections could reveal the remaining structures laying beneath, giving us enough information to reconstruct the complete complex.

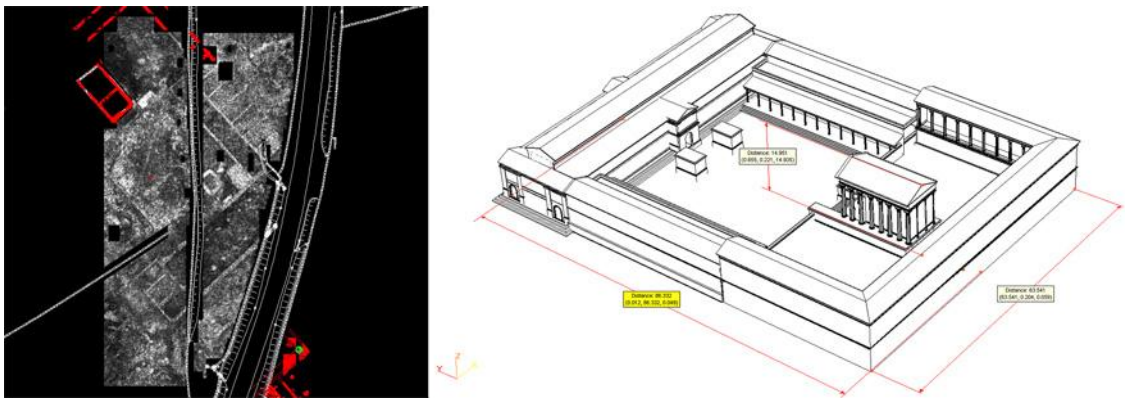

Fig. 11 – Left: Image and interpretation of the geophysical results of the Forum (© Radio-Past). Right: Suggestion for a Reconstruction of the Forum (© 7reasons).

The reconstruction started with the standing and excavated part of the Forum Temple, by searching for suitable comparisons in nearby sites. The Flavian Forum of *Conimbriga* could be used as an overlay, with almost identical dimensions, representing a height of approx. 18 meters (60 Roman feet, from base to the rooftop) whereas the used columns height was set to an idealistic 30 Roman feet (9 meters) leaving us with a perfect height for a “tetrastyle” with four columns on its front side resulting in a 1:2 proportion for its outline. The reconstruction of the temple of *Conimbriga* seemed to be very idealistic and a comparison with the temple of Évora indicated that these ideal proportions where not always used. It seemed that the heights might have been a bit lower than estimated and we, therefore, also redesigned the height of *Ammaia*’s Temple to approx. 15 meters.

The surrounding building of the sacral area is thought to be a *cryptoporticus* on the eastern side of the Forum, due to some indications like the size of the wall and some carefully comnstructed holes found in parts of the excavated walls, pointing to a possible substructure of posts and beams (wood or stone), carrying a floor above. It is not likely to assume a one storey building for the sacral porticoes, since the height of the temple would protrude the overall proportions of the ensemble, giving us opportunity to sketch out a total height of approx. 40 Roman feet (approx. 12 m) supported by columns of 20 Roman feet. The complex of taverns (*tabernae*) connecting southeast to the *cryptoporticus* suggests rather large dimensions of the shops (approx. 6x9 m each) with a portico facing the square of the Forum. It was therefore presumed that two floors existed here, reaching a total height of approx. 9 m (base to roof). A gallery (balcony) in the second floor (5–6 meters above ground) was added to allow light to pass to the rooms of the second storey. In terms of the building functions, this arrangement would allow for a trading and storage area in the basement (shops), extending the shops range by using partly the affiliated porticoes, as shop fronts (show case), while using the rooms of the second floor for administrative purposes.

The most prominent building of the whole complex, the Basilica, used for judicial, negotiation and trade purposes, was positioned opposite to the Temple. It had assumed main entrances in its axis and measured approx. 45x17 m. Since the “radiography” of this area showed, that the interval of the shop-walls continued through the structure on the short faces of the Basilica, we sketched out a protruded entrance, allowing us to line up its roof with the one of the chain of *tabernae*. It can be assumed, that the building had three “floors”, with the Basilicas lighthouse counting as a third floor supported by the columns of the middle ship. The

recommended height was, therefore, assumed to be approx. 12 m. In order to align three axes in the longitude of the Forum complex, the roof of the tavern buildings where thought in continuation of the *cryptoporticus* roof ridge, whereas the centre of the Basilica, with the preferred main entrance, was lined up with the crest of the temple roof. The radiography of the Forum's inner open spaces (market place, sacred place) showed clear indications of several build structures. It can be supposed, that various small shrines and monuments (like votive and decorative elements) were scattered over the square.

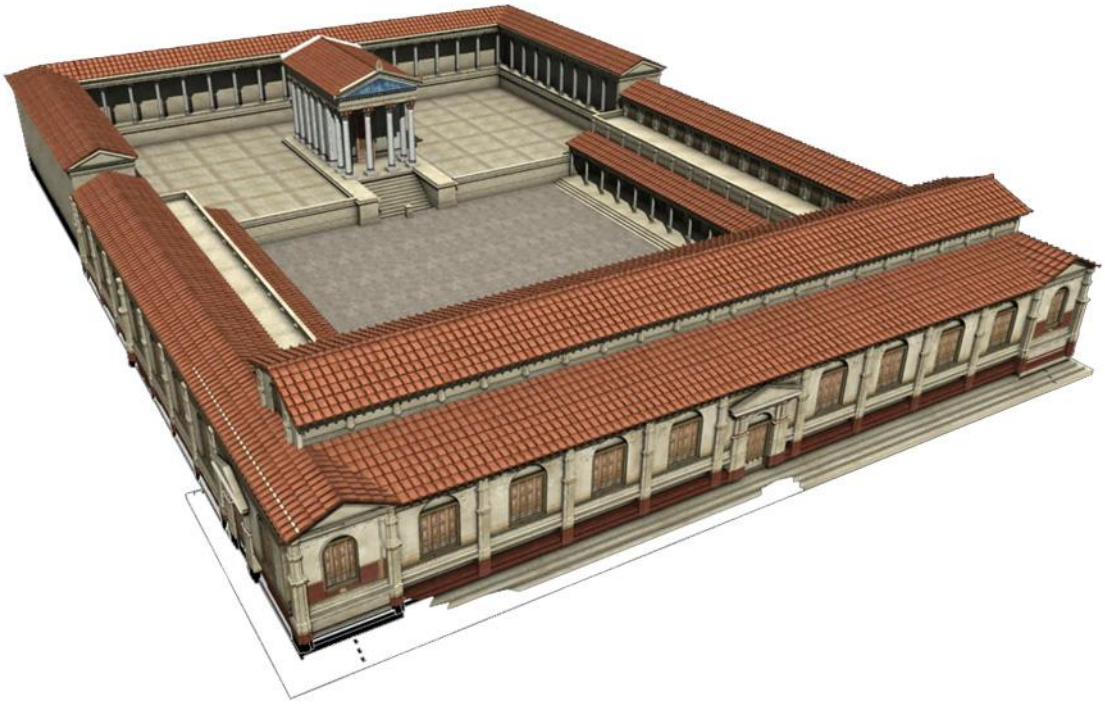

Fig. 12 – Reconstruction of the Forum of Ammaia (© 7reasons).

Reconstruction of the subterraneous remains

The reconstruction of the many still buried ruins of *Ammaia* is approached by using the interpretation of the geophysics results and comparisons of better preserved sites. In order to accelerate the modelling process, a 3D realtime editor (application for videogame production) was adapted to our special needs. The main features of this implementation provide the operator with a library of pre-made house-modules, which can be placed on the digitally imported 3D terrain, where each "block" of the town grid resembles a separate work environment.

The images of the GPR (Ground Penetrating Radar), as well as the results of the Earth Resistance and Magnetometer surveys, where then mapped to the according section of the virtual terrain model.

The preparation of the Building Block library "borrowed" some of the typological features from the nearby site of *Conimbriga,* but also characteristics of the well preserved Italian sites of *Herculaneum* and *Pompeii,* and were adapted to a locally reasonable proportion. This led to an average height of 3,5 m for the first floor and approx 2,5 m for the second floor, resulting in an average overall height of approx 8–11 m from bottom-floor to cornice height. The module structures are arranged to corner-parts (in two directions), middle parts and additive parts like porticos, balconies, gates and minor decorations. With this method we are capable to

sketch out ideas for the final reconstruction, discuss the results within the 3D environment with all team members and make eventual changes quickly. The resulting geometry can be exported to a 3D animation program as soon as a section has reached a satisfying state of reconstruction.

(M. K., G. W.)

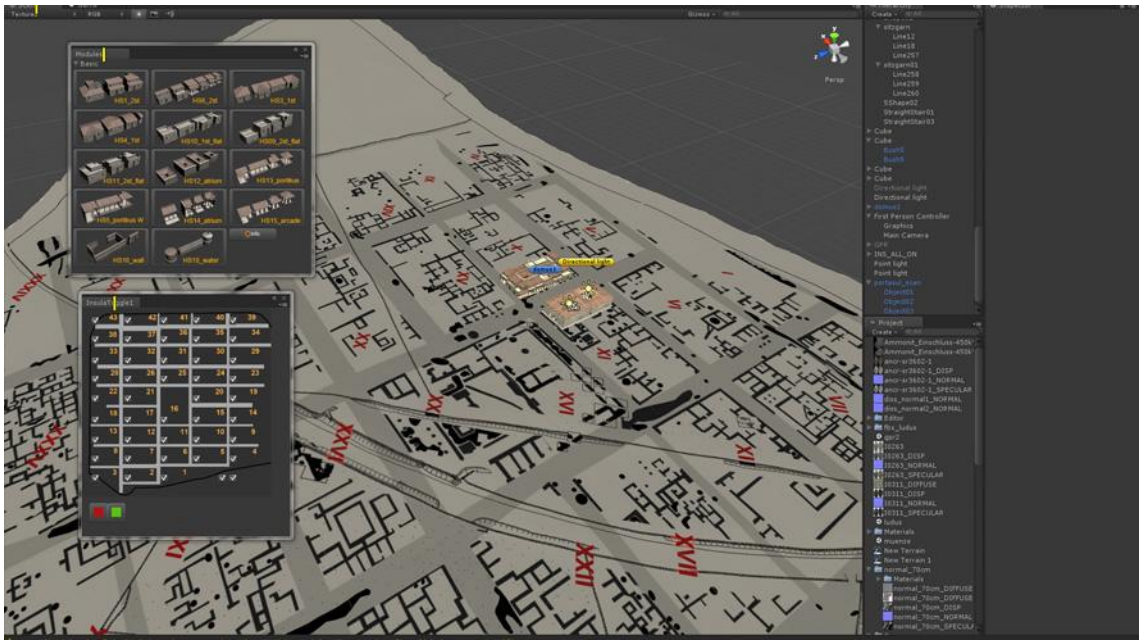

Fig. 13 – Screenshot of the 3d realtime editor with library items and the virtual terrain (© 7reasons).

Fig. 14 – Test result of a layout made from building blocks of the 3d Editors Library (© 7reasons).

Conclusions

As stated above, the reconstructions and visualisations are the result of interactive work and discussion among specialists of different fields (archaeologists, geophysicists, computer specialists, geomorphologists, …) and are based mainly on existing evidence and comparative research. In fact, as in the Past most architecture, especially houses, were built complying to a comparatively uniform code of design, presenting a common tradition of a social class or local tradition, it is easy to integrate excavation results with images of still existing built examples or historical descriptions and drawings. Mostly when working with Roman towns, as it is the case at *Ammaia*, we can rely upon a huge patrimony of available models for public and private buildings, and on the detailed knowledge we have of local traditions and building techniques, and by means of the study of available building materials we can infer many aspects of the existing architectures at a good degree of likelihood (KLEIN et al. forthcoming).

We are well aware that the reconstructions that we present are tentative and experimental, and that new data and ground-truthing or the availability of new tools for data processing could in the future cast doubts or even dismantle our proposals. But this process of confrontation is very helpful in understanding if “things work”: the vision of reconstructed spaces and architectures, the simulation of movements of people and carts along urban streets, the evaluation of relationship between built and open spaces, the estimation of altimetry and slopes can help in putting to the test our interpretations.

Ethically, it is essential that in these reconstructions we clearly state which parts are integrated and which are existing, and this aspect is especially delicate when we deal with a non-specialist public. The matter is much more complex considering that our datasets are already “invisible” as they are predominantly 2D interpretations of geophysical surveys (3D in the case of GPR), and therefore already subject to a high interpretative factor. The distinction for the viewer between “existing” layers of data and reconstruction is, therefore, achieved via the animation, where the spatial referencing of data and the DTM of the site and its surroundings is followed by the progressive building up of volumes and landscape (see, for instance, http://www2.radiopast.eu/?page_id=1831).

One aspect that has been neglected by scholars since the times when reconstructions of archaeological sites and monuments were entrusted to the production of *maquettes,* is the chronological evolution of the settlement. As the transformations and changes were impossible to show, the most common strategy was to choose for the reconstruction of the site in its (assumed) greatest splendour. The best example of this approach is the *maquette* of imperial Rome designed by Italo Gismondi in the late 1930’s and still displayed at the Museum of “Civiltà Romana” in Rome.

This limit of scale models has been surely overcome by the possibility to introduce animations in digital reconstruction, simulating the evolution and transformation of the site, often following the developments until the abandonment and the disruption of the settlement, but this process can be reconstructed only in sites where archaeological research has been collecting a huge amount of stratigraphic data, and this is not often the case.

Of course all these aspects would need a theoretical elaboration and this is why, in the framework of the project Radio-Past, some guidelines for all these matters are under development.

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Archaeological surveys and geophysical prospecting for the reconstruction of the Messapian city walls in Ugento (South Italy, Lecce)

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Abstract: The paper concerns the research activity performed in Ugento (Puglia, Italy) in 2011, aimed to the reconstruction of some sectors of the Messapian city walls (built in large calcareous blocks during the second half of the 4th century BC) and the nearby necropolises, characterized by graves, sarcophagi and stone banks. The modern city overlaps 2/3 of a large Messapian and Roman settlement. The research has involved geophysical prospecting carried out using the Ground Penetrating Radar method and integrated with archaeological and topographical surveys by using a differential GPS. The research was focused on three areas, in correspondence of buried and partially destroyed stretches of the city walls, where GPR surveys were tested in different contexts: one area is a not-cultivated field, in the northern periphery of the ancient settlement; the other two areas are in the sectors of the ancient Ugento now urbanized, in modern roads (Peri and Indipendenza Streets; Petrarca and Mascagni Streets) located along the western periphery of the settlement. The last two areas also regard the remains of two ancient gates, partially excavated in 1980s and now buried.

The GPR data were collected along a dense network of parallel profiles. The GPR sections were processed applying specific filters to the data in order to enhance their information content. Finally, GPR data were visualized in 3D way using both the horizontal depth slices and the iso-surface volumes that representing the 3D variation of the physical properties in the subsoil of surveyed areas. The GPR images significantly contributed in reconstructing the complex subsurface properties in these modern urban areas; in fact, numerous GPR reflections anomalies were correlated with possible archaeological structures. The GPR time slices were georeferenced in the digital archaeological map of the city and the anomalies linked to buried ancient evidence were integrated in the archaeological layers.

Keywords: Urban Archaeology, GPR, Archaeological Map, GIS, GPS.

Introduction. The archaeological map of Ugento: a tool for the historical reconstruction and the urban planning

Ugento (South Italy, Apulia Region, Lecce Province) is one of the most important ancient settlements in the Salento peninsula, which was inhabited by the population of Messapi in the pre-Roman period. It is located at the southern end of a ridge lying parallel to the Ionian coast, which lies 6 km to the west. Although the site appears to have been occupied since at least the 8th century BC, there is no clear evidence of an organized settlement before the 6th century BC. In the second half of the 4th century BC, during a time of intense instability in the area, before the Roman conquest (in the third quarter of the 3rd century BC), the town was

defended by a circuit of walls approximately 4,900 m long that enclosed a very large area of nearly 145 hectares, that make Ugento the largest settlement of the Messapia (Fig. 1). In the Roman age Ugento became a municipality and remained a relatively important town of the Lower Salento. In the Middle Ages the town shrank considerably, with just a castle occupying the highest part of the hill, but it preserved an important role in the area and was the seat of the diocese. The medieval castle of Ugento, with its walls and towers, was still preserved in the early 19th century, as documented a historical map drawn in 1810, that show also a suburb at the eastern slope of the hill; it was built along the so-called Salentina Road, the main route from north to south in the western Salento, which have origin in archaic times. In the late 19th century, the urban expansion resumed, with the modern city now covering two thirds (about 100 hectares) of the area of the Messapian town.

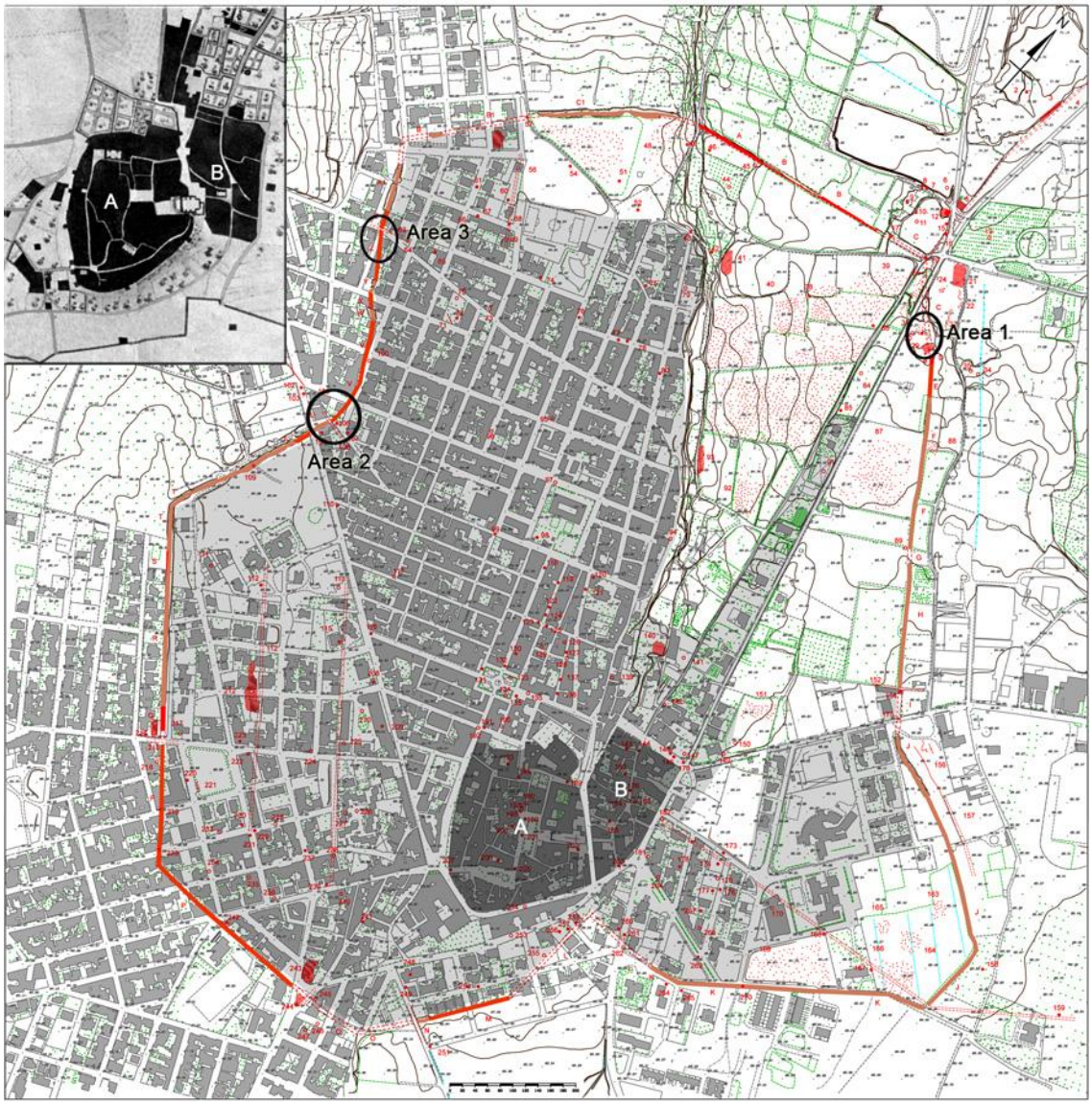

Fig. 1 – The archaeological map of Ugento: in grey the area of the ancient settlement covered by the modern town; in hard grey the extension of the medieval city until the 19th century. The three areas surveyed using GPR in 2011 are also located. In the square was showed a detail of the historical map of Ugento drawn in 1810 by A. Palazzi: the medieval castle (A) and the suburb (B) were documented (the detail is north oriented, while the original map was south oriented).

In the last years, the Institute for Archaeological and Monumental Heritage of the Italian National Research Council (*IBAM-CNR. Istituto per i Beni Archeologici e Monumentali - Consiglio Nazionale delle Ricerche*) has performed in Ugento systematic research activities directed to the creation of a digital archaeological map of the site (CASTRIANNI et al. 2010; SCARDOZZI in print). The research, carried out in cooperation with the University of the Salento (Laboratory of Ancient Topography and Photogrammetry), the Archaeological Superintendence Board of the Puglia Region and the Municipality of Ugento, is based on the integration of different research methods (excavations; archaeological and topographical surveys in the not-urbanized areas; aerial and satellite multi-temporal remote sensing; geophysical prospecting; consultation of literary sources, archive documents and the existing bibliography) aimed to the reconstruction of the ancient settlement, with a view to the conservation, management and appropriate use of cultural heritage. In fact, the archaeological map of Ugento is much detailed and appropriate to the correct and accurate positioning of all the archaeological features identified during the research or already familiar from previous studies; so, the research of the last years allowed the acquisition of a lot of data for the reconstruction of the ancient topography of the town and its transformation during the Messapian, Roman and Medieval periods. But the archaeological map is also a container of organised and georeferenced data integrated in a GIS and it represents an excellent tool for the protection of the archaeological and monumental heritage; in fact it provides support for the proper planning of the city's growth and functions and was integrated in the General Regulatory Plan of Ugento. In addition the map was used to plan measures for the protection and conservation of ancient remains by means of preventive excavations conducted before the construction of new infrastructures or public and private building works. These preventive excavations constitute also a very important occasion to verify, integrate and up to date the archaeological data in the map. Moreover, the map is integrated in a web-oriented GIS (still in progress: see below), aimed to facilitate the data sharing between the Institutions involved in the study and management of the Cultural Heritage in Ugento (Research Institutions and Public Administrations); this data sharing is fundamental for a correct planning of the sectors of the city that are on or nearby ancient features. In this way, the map can be also used for planning measures designed to facilitate the enjoyment of archaeological heritage by the public: for example, itineraries for visitors to the ancient remains that are still visible or virtual tours of the invisible archaeological features.

In 2011 the research in Ugento was focused on some stretches of the Messapian city walls now buried and partially destroyed, with the aim to correct locate their route, verify their state of preservation and understand their characteristics and the extension of necropolises sited nearby the walls and the roads that crossed the fortifications through gates. So geophysical prospecting using Ground Penetrating Radar, integrated with archaeological and topographical surveys using a differential GPS system, were tested in three different areas along the route of the city walls: in the place named Sant'Antonio (area 1), in a not-cultivated field in the north-eastern sector of the fortifications; in Peri and Indipendenza Streets (area 2) and in Petrarca and Mascagni Streets (area 3), both areas now urbanized and sited in the western sector of the route of the wall, where two gates were brought to light in 1980s during very short excavations. Moreover, very important for the study and the reconstruction of the last two stretches of the city walls was the contribution of multitemporal aerial photographs, because they were still preserved in the mid 20th century, as documented by the images taken during flights of the Italian Geographical Military Institute in 1947 and 1955; subsequent

aerial photos taken between the 1960s and 1980s attest their progressive destruction due to the expansion of the modern city without an urban planning regulations that took account of the archaeological evidence.

(G. S.)

From the archaeological map to the webGIS

It is now an established practice, for archaeological research focused on ancient settlements, both characterised by continuity of occupation and abandoned, the use of maps drawn using aerophotogrammetric restitution by specialist archaeologists or cartographers supported by archaeologists (PICCARRETA and CERAUDO 2000; PICCARRETA 2003). These maps have proven to be a fundamental tool for supplying missing information and remedying the inadequacies of the commercial cartography that is often used in the archaeological research. Compared to specialist archaeological photogrammetry, commercial cartography is often not up to date and is drawn on inadequate scales, which may not be large enough to enable precise positioning of the archaeological evidence. In the case of Ugento, the base cartography processed by the archaeologists of the Ancient Topography and Photogrammetry Laboratory of the Salento University, drawn on a scale of 1:2,000, is appropriate to the correct and accurate positioning of all the ancient features. In April and May of 2011, the Ancient Topography, Archaeology and Remote Sensing Laboratory of the IBAM-CNR performed GPS measurements in the whole area of Ugento, aimed to georeferencing in absolute coordinates the archaeological map, surveying some archaeological remains not-documented in the map and positioning the three areas where the GPR measurements were acquired.
The work of georeferencing in absolute coordinates was performed during three different measurement sessions: the absolute coordinates of each remarkable points on the maps and easily identifiable on the ground were taken with the high performance GNNS Sokkia GSR 2700ISX, both in Real Time Kinematik mode and in Continuous Static mode with sessions of 10 minutes for each point. The coordinates obtained from GPS instruments have been mediated through the specific topography software Spectrum® Survey Suite bundled with the GPS, with the aim to obtain 18 couples of absolute coordinates (12 used as Ground Control Points and 6 as Check Points for the operations of rotational shift of the archaeological map).
On this georeferenced archaeological map, the outlines of the areas surveyed by using the GPR were tracked, and the vertices of each area were all recorded by using the GPS. So, it was possible to position with great precision the time slices processed from the GPR measurements in the archaeological map; this work has been particularly useful for the contextualization and correct interpretation of the anomalies in the subsoil linked to ancient buried remains.
In addition, the archaeological map and the documentation of all the ancient features were entered into a webGIS (Fig. 2), still under implementation, in which the map was also engaged with multitemporal aerial photos (1947, 1955, 1968, 1979, 1988, 1998, 2002 and 2006) and satellite images (1970, 2004, 2005 and 2009); the results of the 2011 GPR surveys were also integrated with these data. As cartographic engine of the webGIS, 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 (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 shape file. 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 visualize 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 and processes the request, 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 located in the visualized 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 will be easily accessible from any remote workstation, simply by typing its Internet address.

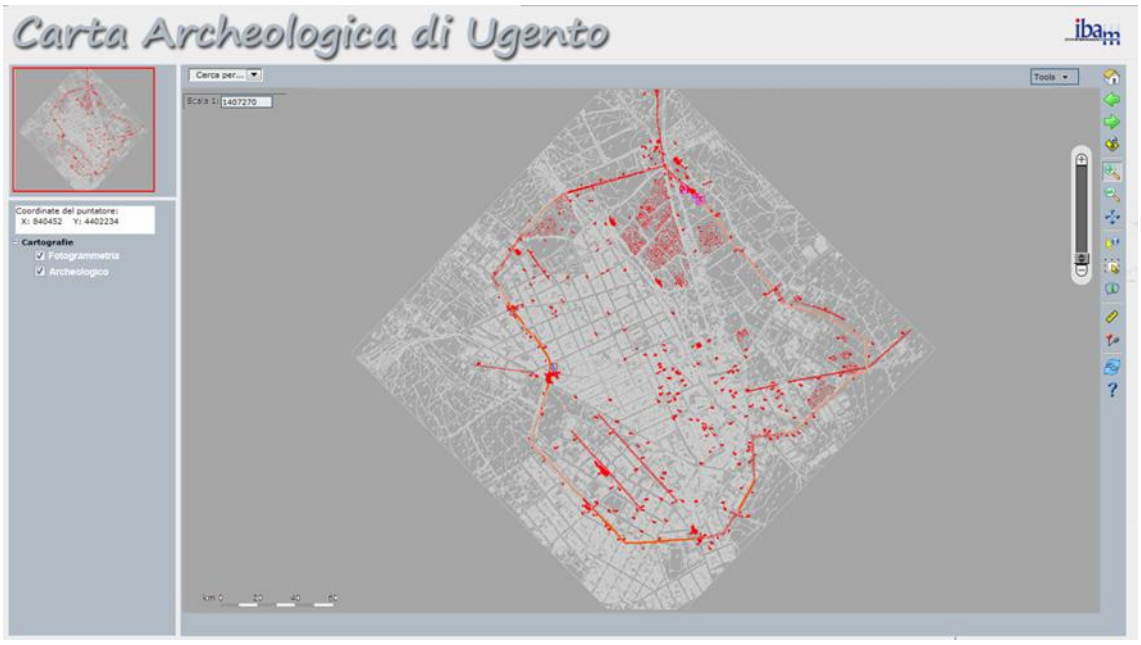

Fig. 2 – The webGIS of the archaeological map of Ugento: each archaeological feature is linked to its description (schedule in pdf format).

The goal is to create a shared internet platform both for scholars and local administration, in which can be integrated the archaeological map and the data related to the ancient remains of Ugento, with a constant data sharing and updating. This platform will not only enhance the possibilities of knowledge and enjoyment of visible and invisible Cultural Heritage of Ugento, but will also allow its careful management and the correct urban planning of the modern city which takes into account the archeological evidence.

(G. D. G.)

The geophysical prospecting in Ugento

Integrated research methods applied in archaeological contest are low encountered in the international literature (PIRO et al. 2003; GAFFNEY et al. 2004; PIRO et al. 2007; LEUCCI 2007; CAMPANA et al. 2009). Ground-penetrating radar (GPR) is currently used to image the subsurface. It is a geophysical method based on the propagation, reflection and scattering of high frequency (from 10 MHz to 1 GHz) electromagnetic (EM) waves in the subsurface. The investigation depth depends on the EM wave attenuation, which increases as the conductivity of the subsoil materials increases, and on the frequencies used: the lower the frequency, the greater the penetration depth, which generally varies from about 1 m to some tens of meters (DAVIS and ANNAN 1989). The GPR method has been successfully used in archaeological prospecting for mapping shallow subsurface objects (CONYERS and GOODMAN 1997; PIPAN et al. 1999; LEUCCI 2002; CARROZZO et al. 2003; CONYERS 2004; LEUCCI and NEGRI 2006; CONYERS and GOODMAN 2007; CATALDO et al. 2012).

GPR surveys, integrated to aerial and satellite remote sensing, archaeological and topographical surveys, were carried out in three areas of the ancient settlement of Ugento. Their purpose was to test the value of radar in respect of penetration depth and, subsequently, to reconstruct the archaeological remains inside the urban contest. The GPR measurements were performed both in not-urbanized and urbanized areas (Fig. 3), that are chosen for a better knowledge of route and characteristics of the Messapian city walls and with the aim to understand the organization of the nearby necropolises.

Fig. 3 – The areas surveyed using GPR: A, Sant’Antonio locality (area 1); B, Peri Street (area 2); C, Indipendenza Street (area 2); D, Petrarca Street (area 3).

The GPR surveys were performed with the IDS Hi Mod GPR system, along parallel profiles at 0.5 m spacing using a 600 MHz centre frequency antenna. The quality of the original data required an appropriate processing for easier interpretation. Processing steps can be summarized as follows: i) amplitude normalization; consisting of the de-clipping of saturated (and thus clipped) traces by means of a polynomial interpolation procedure; ii) background removal; the filter is a simple arithmetic process that sums all the amplitudes of reflections that were recorded at the same time along a profile and divides by the number of traces summed. The resulting composite digital wave, which is an average of all background noise, is then subtracted from the data set; iii) Kirchhoff 2D-velocity migration; a time migration of a two-dimensional profile on the basis of a 2D-velocity distribution is performed. The goal of the migration is to trace back the reflection and diffraction energy to their ‘‘source’’. The Kirchhoff 2D-velocity migration is done in the x-t range; this means that a weighted summation for each point of the profile over a calculated hyperbola of preset bandwidth is performed. The bandwidth means the number of traces (parameter summation width) over which shall be summed.

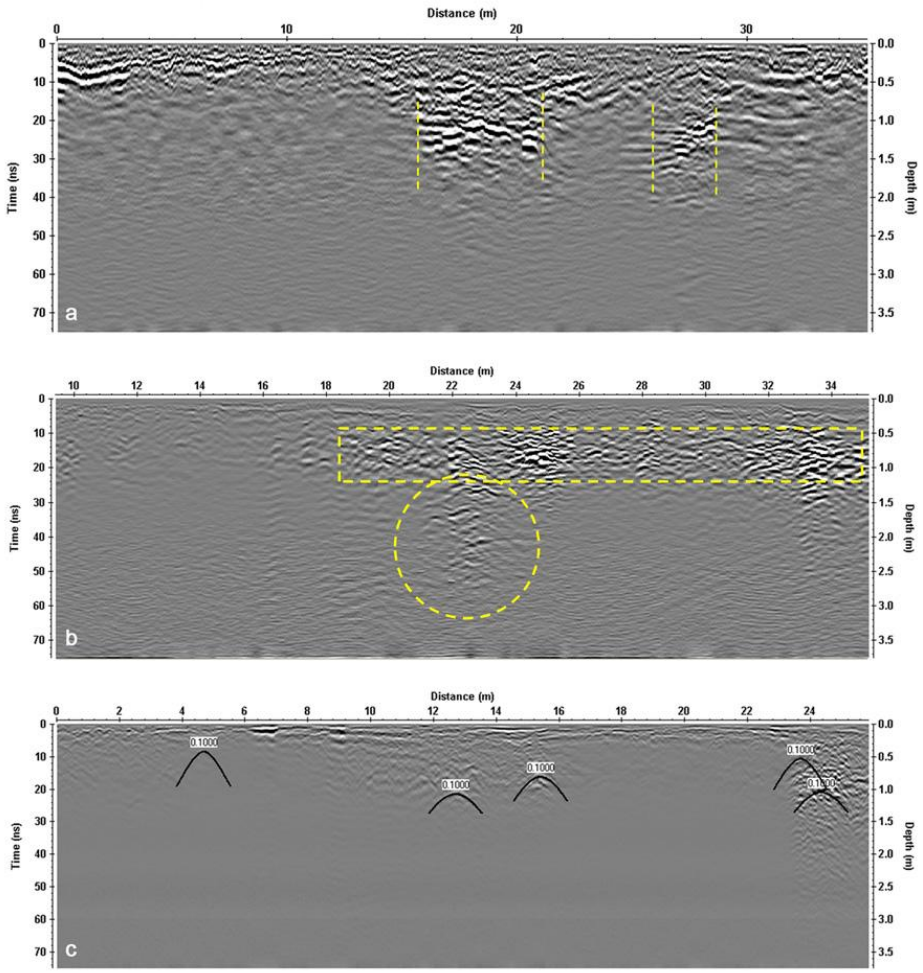

Fig. 4 – Processed GPR data: a–b, two radar sections (in yellow are highlighted the anomalies of archaeological interest); c, an example of velocity analysis performed using the ReflexW 6.0 software (the application of this method points out an average EM wave propagation velocity of 0.10 m/ns).

The processed data were visualized as two-dimensional vertical sections (Fig. 4a–b), depth slices (the depth is between 0 and 6 m) and three dimensional volumes to allow an integrated interpretation of the archaeological results.

A general characteristic of the surveyed areas is a good penetration of the electromagnetic energy (about 70 ns corresponding to a depth of about 3.5 m if the mean velocity value of 0.1 m/ns is used); it is essentially due to the physical characteristics of the subsurface which is characterized by material which is poorly dissipating to the electromagnetic energy. Most of the observed anomalies are confined from about 10 ns to about 50 ns; this is also the case in all the other profiles acquired in the area. The shape and alignment of the anomalies found in the survey area suggest that they are related to the probable presence of archaeological structures.

The EM wave velocity can was determined from the reflection profiles acquired in continuous mode, using the characteristic hyperbolic shape of reflection from a point source (diffraction hyperbola). This is a very common method for the EM velocity estimation and based on the phenomenon that a small object (the dimensions of the object are smaller than the wavelength of the EM wave introduced in the ground), reflects EM waves in almost every direction (FRUHWIRTH and SCHMOLLER 1996). This method is supported by most radar software packages and should be applied if the diffraction hyperbola occurs at least at 20 radar scans (SANDMEIER 2011). Figure 4c shows an example of EM wave velocity determination.

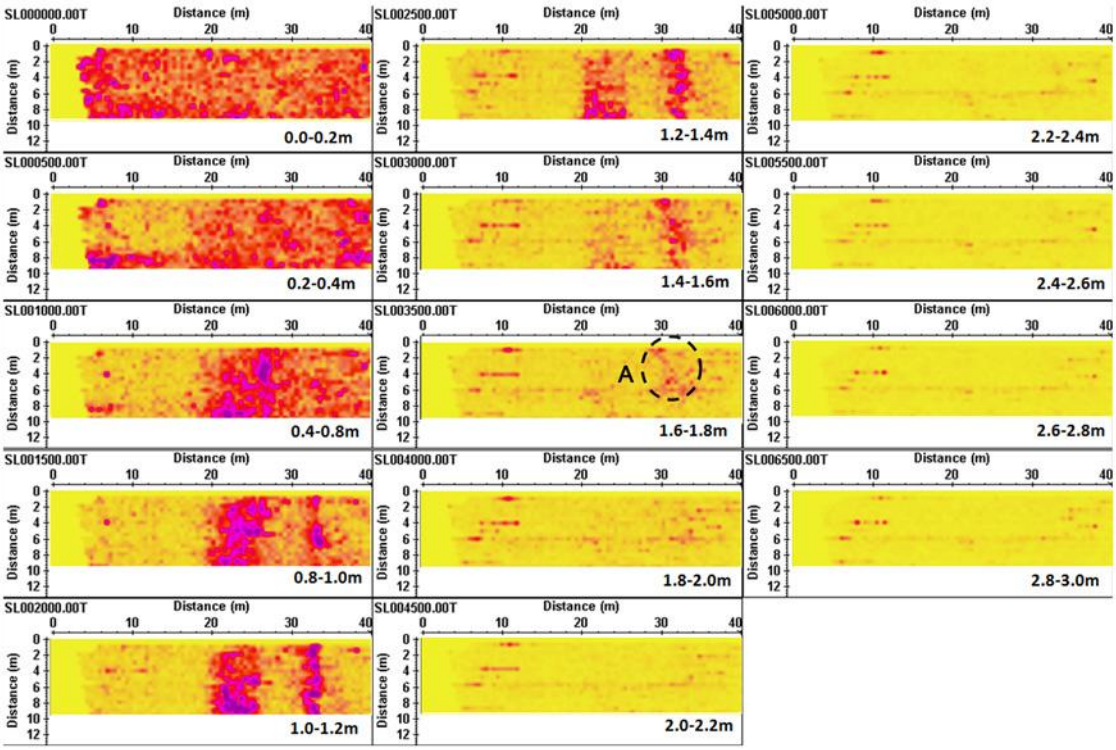

Fig. 5 – Horizontal time slices of the southern sub-area of the area 1 (Sant’Antonio).

A way to obtain visually useful maps for understanding the plan distribution of reflection amplitudes within specific time intervals is the creation of horizontal time slices (CONYERS and GOODMAN 1997). This data representation plays an important role in GPR investigations as it allows an easier correlation of the most

important anomalies found in the area at the same depth, thus facilitating the interpretation. Time slice maps (Fig. 5) are built averaging the amplitude (or the square amplitude) of the radar signal within consecutive time windows of width Δt. Selecting the various parameters involved and in particular the width of the slice, Δt, is crucial. Typically Δt must be of the order of the dominant period, but different widths can be used in order to enhance particular features. In common practice, non-overlapping time windows are chosen, although sliding windows could be used instead, with the advantage of greater resolution but higher computational costs. In the present work the time slice technique has been used to display the amplitude variations within consecutive time windows of width Δt = 4 ns. The selected two-way time interval corresponds to a soil layer, approximately 0.20 m thick, and the time slices are located between 0 and 3.5 m in depth. The depth slices were georeferenced in the archaeological map thanks measurements take using a differential GPS with high precision.

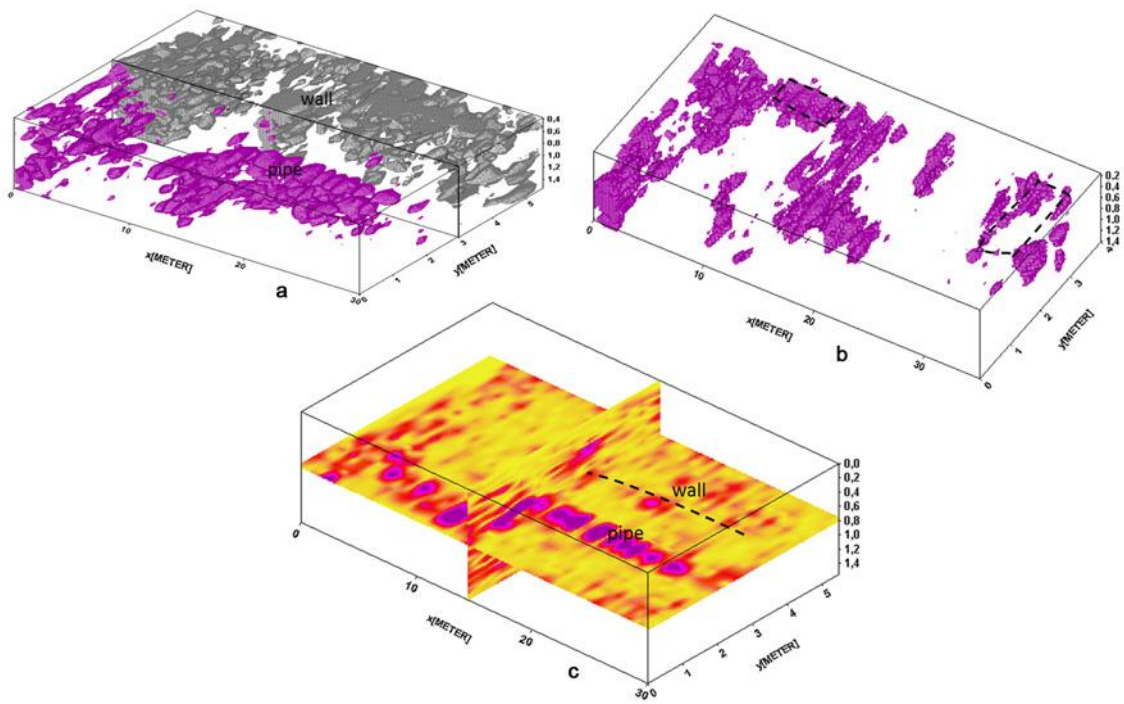

Fig. 6 – 3D visualization of GPR data (a–b) by means of iso-amplitude surfaces and pseudo 3D visualization (c) of the 2D processed radar sections.

One approach for visualizing 3D radar data has been proposed by ZANZI and VALLE (1999) for automatic mine detection. In this case, after an appropriate processing of radar data, a 3D image of the sought diffracting or reflecting object could be easily obtained by: i) extraction of a particular complex signal attribute (trace envelope); the grid data are converted to the reflection strength or amplitude envelope by a Hilbert transformation; ii) thresholding: a threshold value must be entered. Hence all amplitudes greater/equal than this value are considered per definition; iii) 3D contouring by means of iso-amplitude surface. As pointed out by the authors, in this case the threshold calibration is a very delicate task. In Fig. 6 the data set acquired in the area 2 and 3 is displayed with iso-amplitude surfaces using 40% of the maximum complex trace amplitude threshold value. Obviously, lowering the threshold value, it increases the visibility of the main

anomaly and smaller objects, but also heterogeneity noise. Relatively strong continuous reflections are visible on the threshold volumes. This visualization technique put better in evidence the anomalies found in the area.

(G. L.)

The contribution of geophysical prospecting to the study of the Messapian city walls

The archaeological map of Ugento is a dynamic tool and is constantly updated with data from new excavations or surveys. In 2011, geophysical prospecting using GPR was performed to support the archaeological research in three peripheral areas of the ancient city and were aimed to verify route, characteristics and preservation of the Messapian city walls in stretches now buried or covered by modern roads and houses. The integrated geophysical, archaeological and topographical surveys were tested both in not-urbanized and completely urbanized areas and had good results; they also clarify some contexts where ancient tombs are nearby the fortifications.

The Messapian city walls, built in the second half of the 4th century BC, enclosed a large surface including both the hill where the Archaic settlement lied (today is the ancient center of the modern town) and the large plains down the eastern, southern and western slopes of the same hill (these plains lay at an altitude until 25 m down the top of the hill). The area enclosed by the city walls probably was not entirely inhabited in ancient times, but it was also characterized by the presence of gardens and necropolises; in fact, in the Messapian settlements tombs are often near the houses and inside the urban areas. In particular, in Ugento, during the 4th and 3rd centuries BC, when the city was defended by the walls, the necropolises were generally in the peripheral sectors along the roads that left the urban area, both outside and inside the gates.

Fig. 7 – Stretch of the external side of the Messapian city walls.

Today, about half of the city walls are preserved, in particular in the northern, eastern and south-western peripheries of the ancient settlement, in areas not covered by the urban expansion of the last half century. Generally these stretches are buried or covered by modern boundary walls built using small irregular stones and by modern roads that use the remains of the ancient walls like foundation. The internal or external sides are visible only in a few points of their route (Fig. 7). Systematic excavations regarding sectors of the city

walls were never carried out, but a few stretches were brought to light thanks some small-scale excavations applied in response to the execution of public works or the construction of private buildings.
Generally the city walls are 6–7 m wide, but in some points they also reach a wide of 8.5 m; they are constituted by an external and an internal structure built in very large square blocks, in local calcareous stone; the space in the middle is filled up with small irregular stones mixed with soil (the so-called *emplekton*). The only exception is a short stretch, excavated in the place named Sant'Antonio, where the walls are built only with blocks in their entire wide. Some gates were opened along the city walls; two of these were brought to light thanks very small excavations, in Petrarca and Peri Streets. The city walls were reinforced by some towers, showed in the historical maps of Ugento (Fig. 8); one square tower was excavated immediately south the gate of Peri Street.

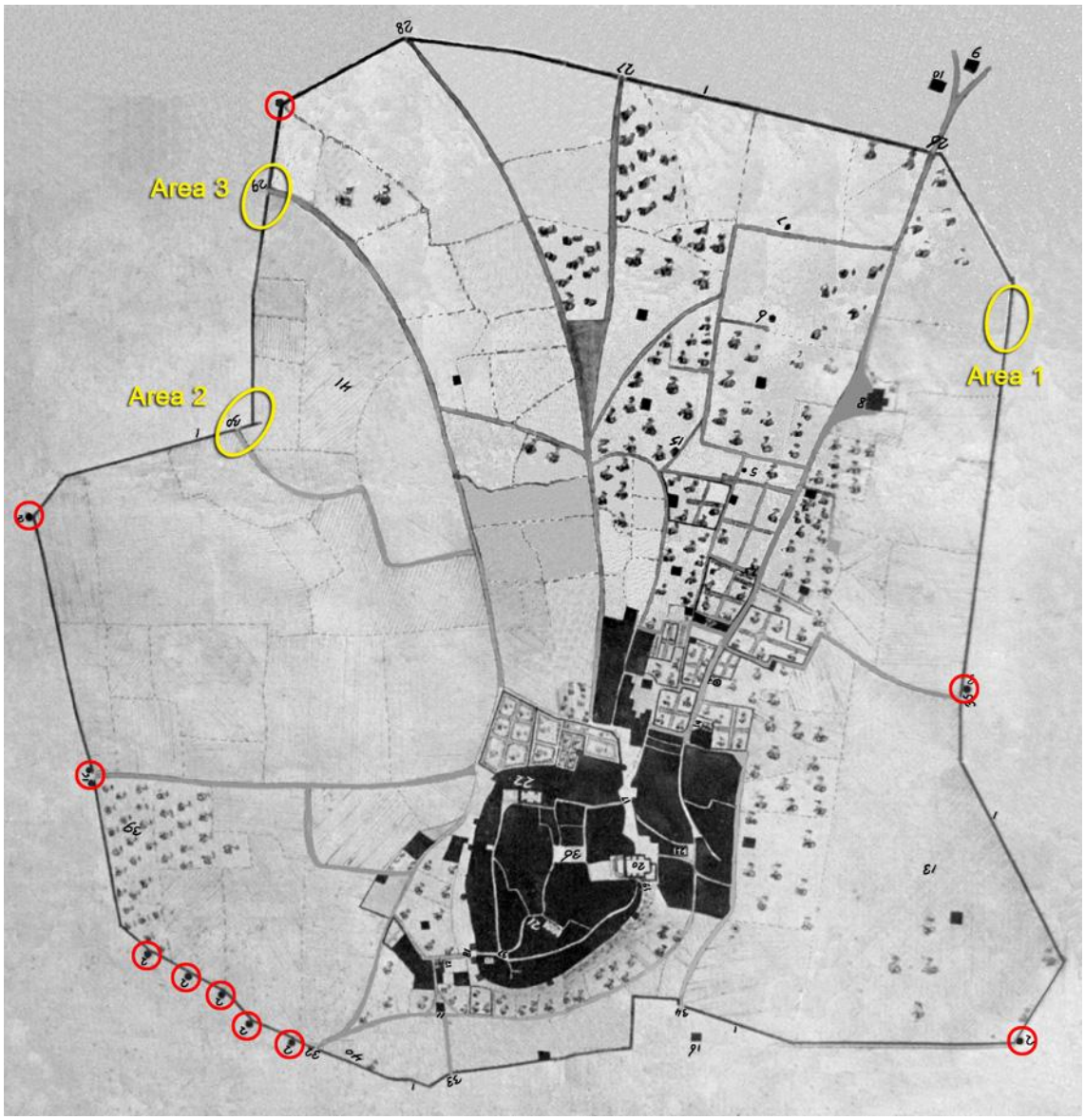

Fig. 8 – Detail of the historical map of Ugento drawn in 1810 by A. Palazzi: some towers (red circles) are documented along the Messapian city walls, where the positioning of the areas surveyed using GPR is also highlighted (yellow circles) (the detail is north oriented, while the original map was south oriented).

The GPR measurements were performed in three areas in the north-eastern (Sant’Antonio area) and western sectors (Peri and Indipendenza Streets; Petrarca and Mascagni Streets) of the city walls, with the aim to better know these stretches (now buried and partially destroyed), as route, characteristics of the structure (gates, towers, offsets to the outside), and the organization of the necropolises nearby the fortifications (in particular, inside them, along the roads the crossed the fortification via the gates).
In the Sant’Antonio area (Area 1), GPR acquisitions were performed in April 2011 in three sub-areas (Fig. 9) nearby the excavated surface where in 1986 and 1987 were found about 30 graves, carved into the rock and with a covering in large calcareous slabs. The grave goods (mainly pottery and some metal objects) allow their dating between the 4th and the 3rd century BC; a few graves have traces of paint. The tombs appear to be distributed in parallel to the short stretch of the walls (16.50 m) partially brought to light. Only exception is a tomb of the second half of 6th century BC; it has a different orientation and it is located along the layout of the walls. In this sector, the city walls are built using only blocks in their entire wide (6 m) and they are preserved for one or two rows in height; they rest upon the ground or the smoothed bedrock and lie under a slight burying. A topographical survey of graves and walls using a differential high precision GPS was performed in 2011.

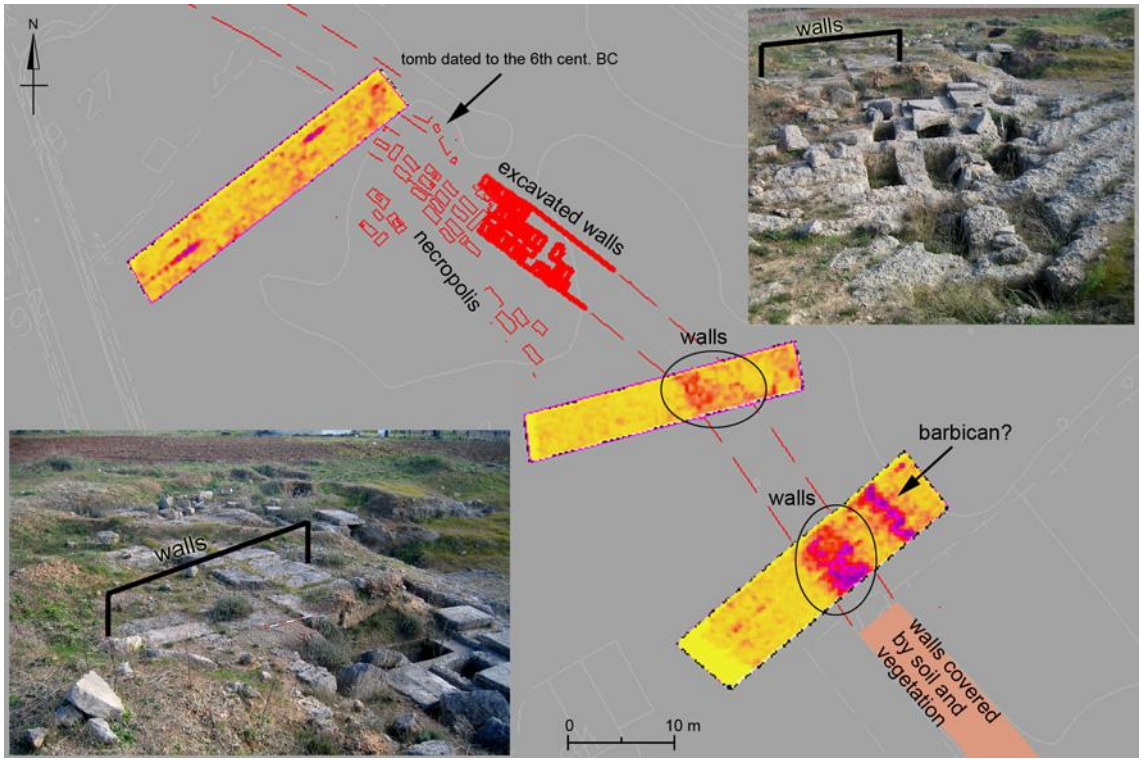

Fig. 9 – Sant’Antonio area: time slices at a depth of 80–100 cm georeferenced in the archaeological map; in the squares, the tombs and the stretch of city walls excavated in 1986–1987.

The GPR acquisitions were made in two sectors south of the excavated area and one sector to the north. The acquisitions sections have a direction orthogonal to the city walls. Remains of these walls are identified in the two southern sectors at a depth between 40 and 100 cm, where they continue the excavated stretch with the same line. This stretch of the fortifications was still preserved at the end of the 19th century, as

documented by the historical maps (Fig. 10); its traces (soil marks) is also showed by an aerial photo taken in 1947, when the walls were already destroyed. The GPR measurements also highlight anomalies probably linked to a barbican sited to the west of the walls. A rectangular structure is visible more in depth (1.6–1.8 m; see above Fig. 5, A), down the possible barbican; considering the dimension and the shape, it is perhaps a tomb like the one preserved a few metres further south, outside the walls. There aren't traces of other tombs both inside and outside the walls.

Fig. 10 – Sant'Antonio area: the stretch of the city walls documented in the historical map of Ugento drawn by G. Epstein in 1897; its traces (clear fragments of the calcareous blocks notched by ploughings) are also visible in an aerial photo of 1947.

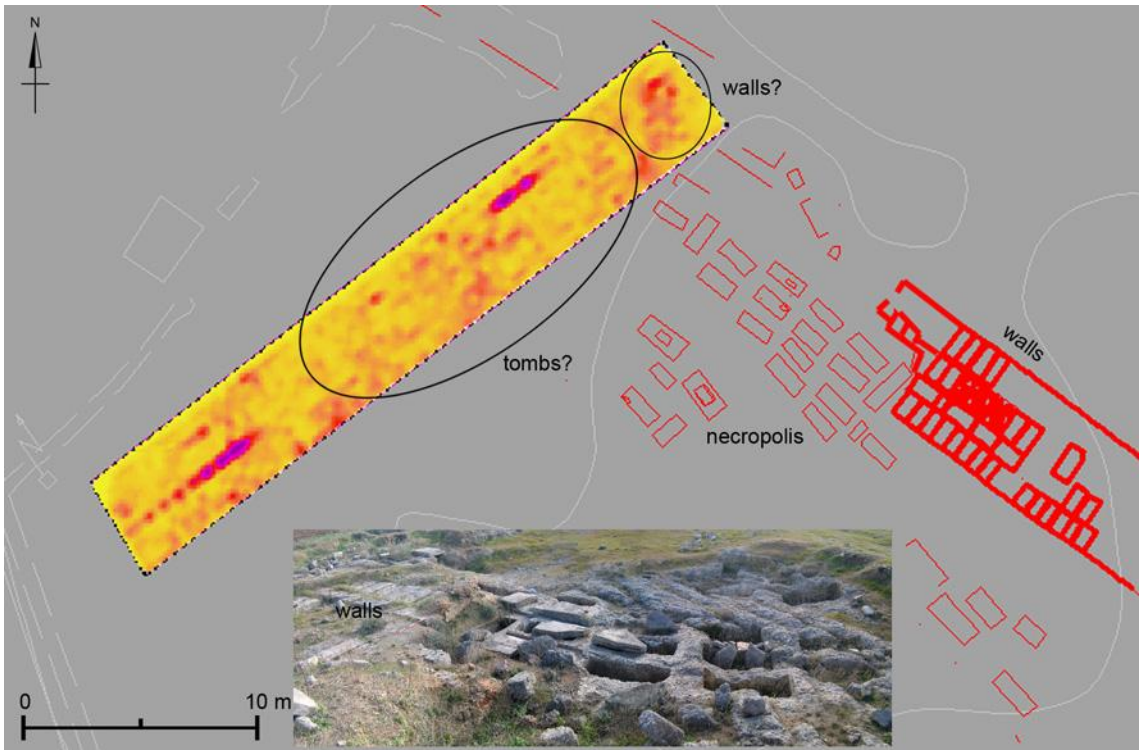

Fig. 11 – Sant'Antonio area: time slices at a depth of 120–140 cm of the northern sub-area, georeferenced in the archaeological map.

To the north of the excavated area, anomalies linked to the walls are not visible; in this point, probably they were offset to the outside (this type of route is documented in other sectors of the city walls, in particular near the gates). Some anomalies that can be related to graves are visible particularly at a depth of 120–140 cm (Fig. 11); they continue the necropolis inside the walls in north direction. This hypothesis could be confirmed by the presence of other tombs a few meters further north-east and east; they are partially destroyed by modern quarries and cut by the new road between Ugento and Casarano, built in the 19th century.

Fig. 12 – The surveyed sub-areas (in azure) in Peri and Indipedenza Streets, georeferenced in the archaeological map (in pink the preserved stretches of the city walls, in orange the buried or destroyed stretches).

The second investigated area is in the western side of the city walls and concerns two stretches of Peri Street and the surrounding areas along Indipendenza Street (Fig. 12). This sector of the modern town was built during 1960s and 1970s, when the Messapian city walls were progressively destroyed; the aerial photographs of 1940s and 1950s document that they were still well preserved, while subsequent images show their destruction (Fig. 13).

A stretch of the city walls with a gate was discovered in Peri Street (immediately under the asphalt), near the corner with Giannuzzi Street, during excavation works for the sewage system in 1985 (Fig. 14); only a course of the walls was preserved and based on the virgin soil, at a depth of 75 cm. They were 6.40 m wide and constituted by an internal structure built with one line of blocks and by an external structure built with two lines of blocks; in the middle there was a structure composed of irregular stones mixed to earth. Immediately outside of the city walls there was an escarpment structure also constituted by irregular small stones.

Fig. 13 – Aerial photos of 1947, 1955, 1968 and 2002 that document the progressive destruction of the Messapian city walls in the surveyed areas of Peri and Indipendenza Streets (Area 2) and of Petrarca and Mascagni Streets (Area 3); the arrows indicate the preserved stretches of the city walls and the routes of Peri (A) and Petrarca (B) Streets, that follow two ancient roads also documented in the historical maps (see Fig. 8).

The gate of Peri Street (it is documented also in the historical maps, where there is not the tower: see above Fig. 8) was about 3 m large; in its southern side there was a rectangular tower (5.30 x 3.50 m) completely built with blocks. In the northern side was discovered a structure also built using square blocks; it protrudes outward from the walls line. So it is possible that in this point there was an offset to the outside of the fortifications, as in other gates of the ancient Ugento and of other Messapian settlements. Again on the northern side of the gate, immediately inside the city walls, another structure in blocks was discovered, maybe used by military guards.

The ancient road that crossed the gate was parallel and immediately to the south of the modern stretch of Peri Street, with an east-west axis. Numerous tombs dated to the 4th and 3rd century BC there were along the northern and southern sides of this road; they were sarcophagi and crate built with stone slabs. These tombs were discovered during some building works between 1960s and 1980s, both in the urbanized areas surrounding Peri Street and under the same modern road, where 12 tombs were found in 2004–2005 at a

depth of 80 cm (Fig. 15). Other tombs were discovered immediately outside the city walls along the two sides of the same ancient road that crossed the gate of Peri Street.

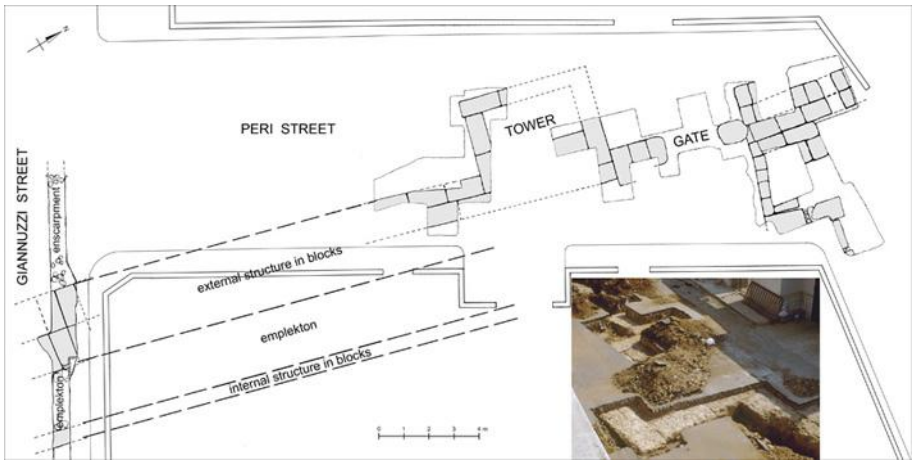

Fig. 14 – The stretches of the city walls excavated in Peri Street in 1985; a detail of the tower is visible in the photo.

Fig. 15 – The tombs (T) excavated in Peri Street in 2004–2005 (the plan was edited by *Studio di Consulenza Archeologica – Ugento*).

The geophysical surveys carried out in May 2011 were aimed to verify the route and preservation of the city walls and the presence of other tombs in this area, in particular near the internal side of the fortifications. The GPR measurements in Peri Street have highlighted the buried remains of the walls and their offset to the outside at a depth between 50 and 150 cm (Fig. 16). The horizontal time slices also show anomalies corresponding to the tombs brought to light in 2004 and 2005, and to other tombs of the same type that

continued the necropolis in east direction, where a crate built with stone slabs dated to the 4th–3rd centuries BC was found in 1965 at the east corner between Peri Street and Indipendenza Street. Anomalies corresponding to sewer pipes are also visible; they partially cut the ancient structures. The third sector of this investigated area is a stretch of Indipendenza Street; a corner of the city walls (that turned in north direction) was highlighted by GPR measurements at a depth of 3 m. Inside the urban area other anomalies at a depth between 50 and 200 cm are probably linked to one or more tombs of the same type of those in the nearby necropolis of Peri Street (Fig. 17); it is important also to highlight that in 1989 a sarcophagus of the Late Archaic age was found a few meters further north, in the same Indipendenza Street, inside the city walls.

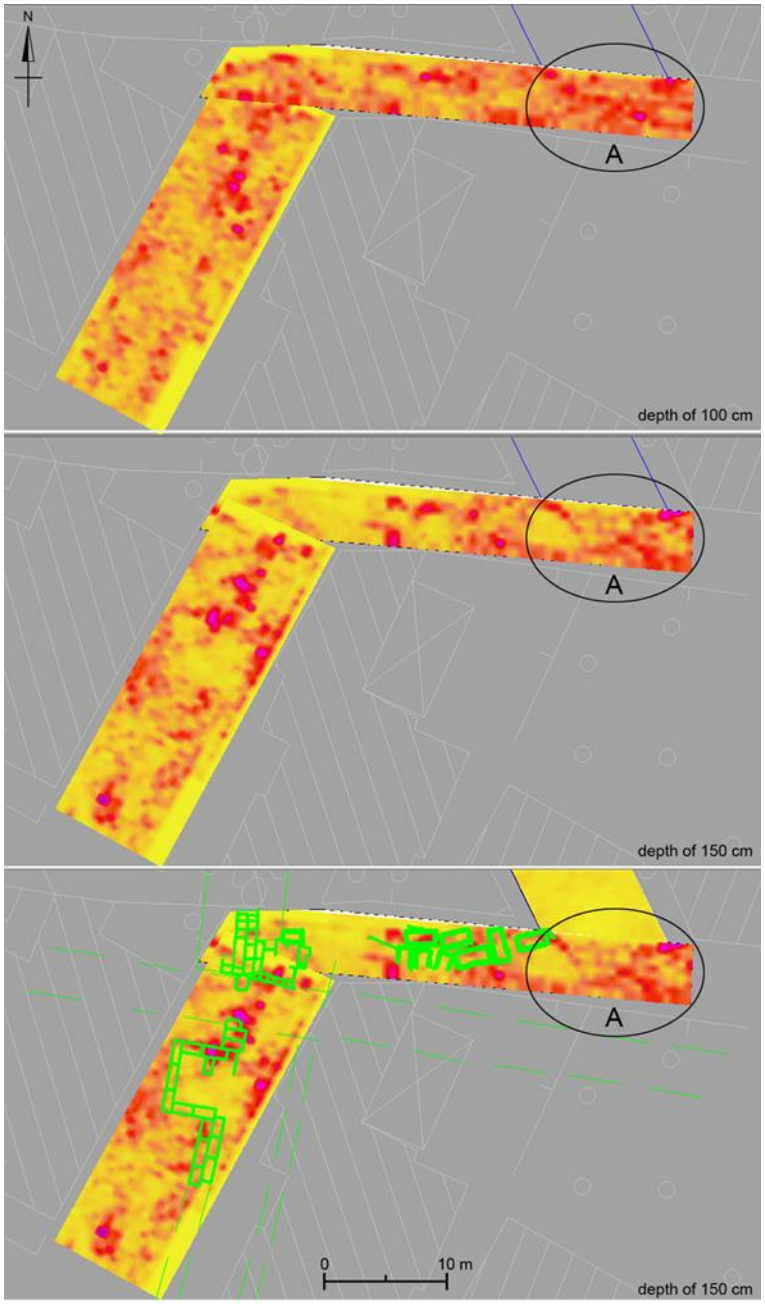

Fig. 16 – Peri Street: horizontal time slices at a depth of 100 and 150 cm; in green the plan of walls and tombs excavated in 1985 and 2004–2005. A, anomalies probably linked to other buried tombs.

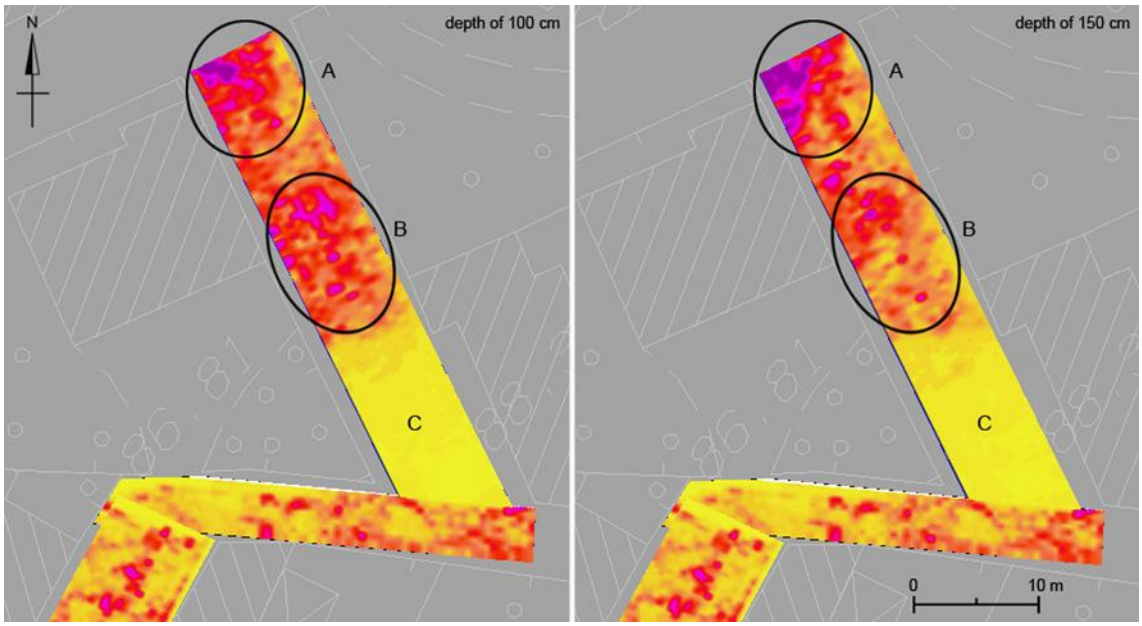

Fig. 17 – Indipendenza Street, horizontal time slices at a depth of 100 and 150 cm: A, corner of the city walls; B, tombs (?); C, area with a no good penetration of the electromagnetic energy.

Fig. 18 – The surveyed sub-areas (in azure) in Petrarca and Mascagni Streets, georeferenced in the archaeological map (in pink the preserved stretches of the city walls, in orange the buried or destroyed stretches).

The third investigated area is again along the western side of the city walls, at the corner between Petrarca and Mascagni Streets (Fig. 18). The urban expansion of the modern town during 1960s and 1970s have destroyed also this sector of the ancient settlement together with the remains of the fortifications, that are showed still preserved in the aerial photos of 1940s and 1950s (see above Fig. 13); the images of subsequent years document the progressive destruction of the ancient evidence. Today only a few sectors are preserved, mainly buried in small fields included in the urbanized environment. A short stretch of the city walls was discovered in 1984-1985 during excavation works for the sewage system (Fig. 19); in this point a gate was found at a depth of 70 cm; it was 2.25 large and closed with blocks in the 3rd century BC. The historical maps document also this gate (see above Fig. 8).

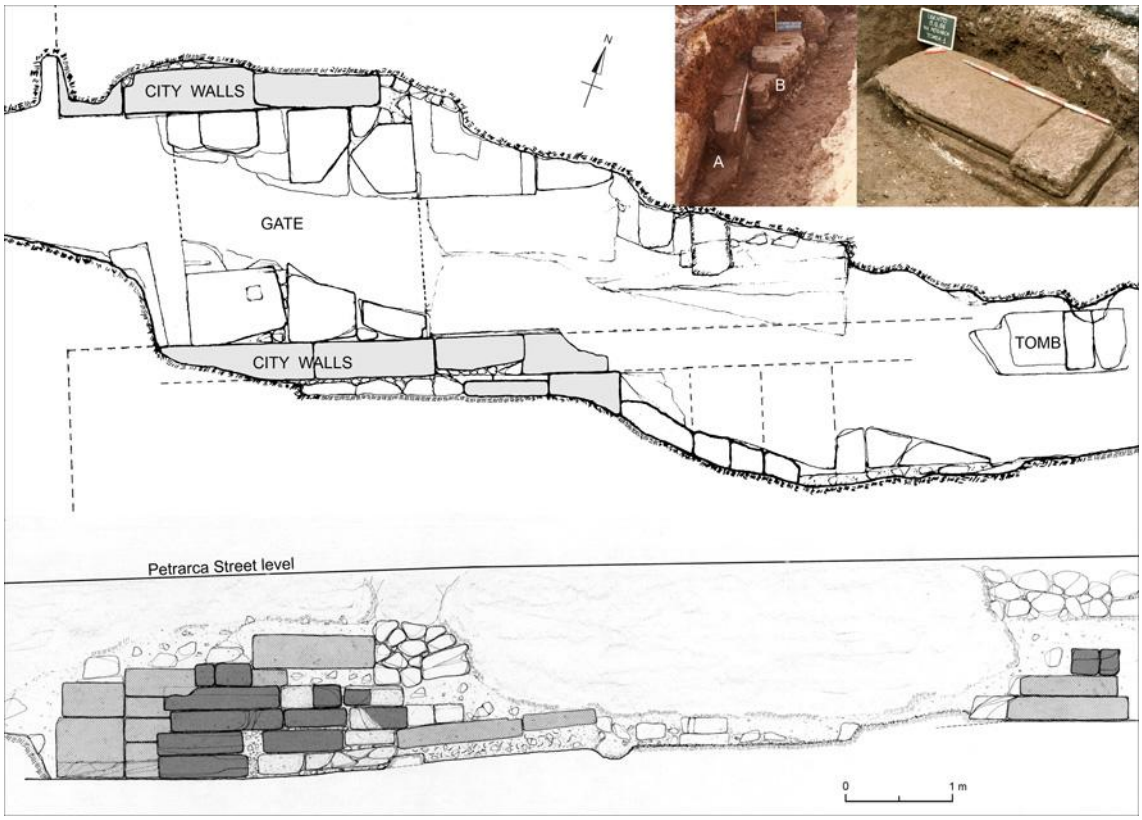

Fig. 19 – Petrarca Street: plan (1) and section (2) of the remains of the city walls brought to light in 1984–1985; the photos show the structure (A, blocks of the gate; B, blocks of its enclosure) and the tombs found inside the fortifications.

An offset to the outside of the fortifications was immediately to the north of the gate; instead, on its southern side it was impossible to understand the situation and the possible presence of a tower like in the gate of Peri Street due the very short excavated area. One tomb dated to the 4th century and built using stone slabs was found immediately inside the city walls, along the southern side of the ancient road that crossed the gate.

The GPR measurements in Petrarca Street document anomalies at a depth between 1 and 2 m that can be related to the northern side of the gate (Fig. 20). It is today crossed by the sewer pipe, clearly visible in the horizontal time slices. The GPR acquisitions in Mascagni Street show a few anomalies linked to the blocks of the external structure of the walls, while the sewer pipe is again well visible just outside the fortifications.

Anomalies that can be related to tombs or a possible tower to the south of the gate are not visible (no tower is documented in this stretch by the historical maps).

(G. S.)

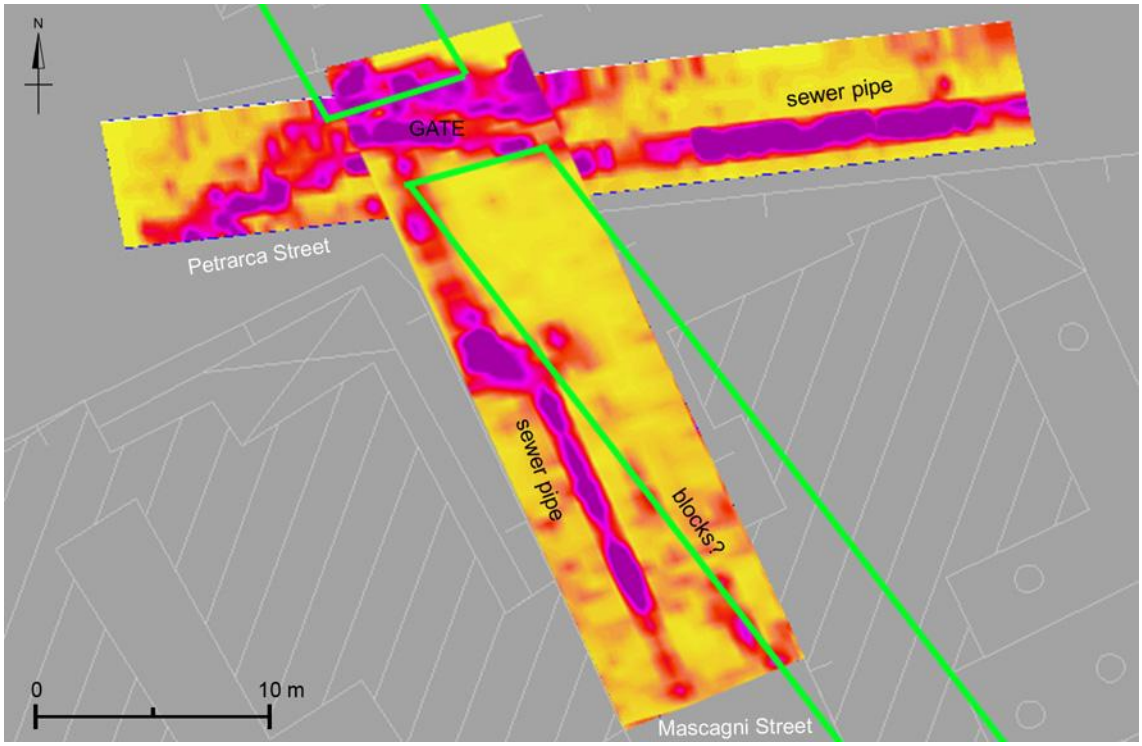

Fig. 20 – Petrarca and Mascagni Streets: horizontal slices at a depth of 150 cm. The route of the city walls (in green) is reconstructed thanks the vectorization of the remains that are visible in the aerial photo of 1947, georeferenced in the archaeological map.

Conclusions

The GPR measurements tested in some areas of Ugento during 2011 have highlighted that it is very important to integrate these acquisitions to the other research methodologies applied in urban archaeology, in particular excavations and surveys. The research allowed to update the archaeological map of the ancient settlement and to acquire new interesting data about route and characteristics of the Messapian city walls; important documentation about the necropolises located in the peripheral areas, near the gates, were also acquired.

In particular, in the area 1 (Sant’Antonio) GPR measurements documented: i) the preservation of the buried city walls south of the excavated stretch of the fortifications; ii) the presence of a possible barbican external to the city walls; iii) a possible offset to the external in their route; iv) the continuation of the necropolis in north direction.

Some interesting results were also acquired in the area 2. In Peri Street were documented: i) the preservation of the buried city walls; ii) the offset to the external in their route to the north of the gate; iii) the continuation of the necropolis in east direction. In Indipendenza Street were also highlighted: i) the preservation of the buried city walls and the precise location of their corner; ii) the possible presence of tombs inside the fortifications.

Lastly, in the area 3 (Petrarca Street and Mascagni Street) were documented: i) the preservation of the buried city walls; ii) the offset to the external in their route to the north of the gate; iii) the absence of a tower to the south of the gate.

(G. S.)

Acknowledgment

The archaeological map of Ugento was produced thanks the suggestions and cooperation of Profs. Marcello Guaitoli and Francesco D'Andria (University of Salento, Department of Cultural Heritage), Drs. Giuseppe Andreassi and Assunta Cocchiaro (Archaeological Superintendence Board of the Puglia Region), and Dr. Massimo Lecci (Municipal Administration of Ugento). The base cartography for the archaeological map of Ugento was drawn by Dr. Veronica Ferrari under the supervision of Prof. Giuseppe Ceraudo (University of Salento, Laboratory of Ancient Topography). In the IBAM-CNR research activities focused on the webGIS of Ugento and the geophysical surveys also work Drs. Ilaria Miccoli and Veronica Randino. During the research was very important also the cooperation with the *Studio di Consulenza Archeologica* in Ugento, directed by Paolo Schiavano.

All the authors have cooperated in the data acquisition and interpretation. Moreover, G. Di Giacomo has implemented the webGIS and has performed the 2011 up-dating of the archaeological map; G. Leucci has processed the GPR data; G. Scardozzi has coordinated the research and the archaeological study.

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Geophysical Surveying in Urban Centers of Greece

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Abstract: Geophysical techniques have been increasingly applied within the complex urban fabric for addressing a number of questions related to the location of architectural monuments or the conservation status of buildings. Still, modification of geophysical techniques is needed, whereas only a limited range of them, such as GPR, soil resistance and 2D/3D ERT, can be employed in order to acquire valuable information and within the "urgent" time limitations that sometimes exist due to the course of construction works. Anthropogenic noise, disturbed geological settings and modern interventions contaminate the geophysical signals which sometimes produce ambiguous results and interpretation of the data turns out to be a difficult task. Furthermore, each method needs to be adapted to the matters addressed by the survey questions and the monuments involved.

The particular paper will manifest the significance of the application of geophysical surveying in various urban centers of Greece. Examples will be drawn in the context of civil and private construction works, surveillance of monuments, examination of standing buildings and monuments and the analysis of regional risk assessment of monuments via the use of geophysical methods. In each case, the application of geophysical techniques, sometimes in close consideration to other information such as older testimonies and maps, has resulted in valuable conclusions with respect to the stability status of monuments or the subsurface localization or expansion of relics.

Keywords: Geophysical, urban archaeology, resistivity tomography, GPR, risk assessment.

Introduction

It is commonly known that many modern urban centers exhibit an alternative archaeological and historical dimension justified by the numerous historical, visible and standing monuments as well as the possible archaeological structures that are still lying beneath the urban subsurface. A distinct feature that characterizes the developing countries is the constantly on-going urbanization. The economic growth has inevitably led to the construction of modern infrastructures, new building facilities as well as large or small public or private works, within the territory of urbanized centers. Thus, it is straightforward that archaeological monuments and residues from past anthropogenic activities that are contained within the subsurface matrix of urban centers, are usually discovered during the progress of these construction activities. Furthermore their exposure becomes responsible for the delay of the related actions, while at the same time there is a number of questions not only related to the location or extent of architectural monuments, but also with the conservation status of buildings and the risk assessment management of the historical/archaeological architecture.

The sector of geo-informatics provides new technological innovations in the service of urban archaeological research. Innovative satellite recording systems, improved processing algorithms of digital images, three dimensional (3-D) modeling and virtual reality, data integration, management and spatial analyses within Geographical Information Systems, expand the possibilities in mapping archaeological sites and protecting archaeological monuments (PAPADOPOULOS et al. 2010).

Among geo-informatics, the geophysical prospection methods are nowadays frequently applied within the context of surface surveys (GOURLEY et al. 2008), in guiding systematic and surveillance excavations (PARKINSON et al. 2010) or within the progress of large construction works (PAPADOPOULOS and SARRIS 2010). Recent geophysical applications include the capturing of the integrity degree of standing monuments (PAPADOPOULOS and SARRIS 2011; TSOURLOS and TSOKAS 2011) or investigating the complex changes of the physical urbanized environment giving rise to the relatively new study field of "urban geophysics" (PAPADOPOULOS et al. 2009; DRAHOR 2011).

In a few cases, part of the results of the geophysical prospection campaigns is tested and verified through immediate excavations that follow. In other cases the geophysical results are integrated with descriptions, plans and sketches of ground plan monuments compiled by past travelers, importing a new dimension in the urban archaeological research by verifying diverse historical sources and testimonies and rediscovering the location of previously excavated monuments (PAPADOPOULOS et al. 2012). Furthermore, in most sites, the information that exists about the underground monuments is almost nonexistent and geophysical techniques bring new and sometimes surprising archaeological indications (SARRIS et al. 2007).

Although geophysical methods can effectively fill the gap between the construction development and the archaeological monuments' preservation by providing a non-destructive tool for cultural resources management, the geophysical survey in an urban area may face some objective difficulties. These problems arise from: a) the high level of ambient noise caused by electrical currents, magnetic interferences, acoustical noise and electromagnetic radiation masking to a certain degree the valuable archaeological signatures, b) the highly heterogeneous nature of the upper ground layers that may hinder the accurate mapping of archaeological structures, and c) the limited time window to conduct a detailed survey, which in conjunction with restricted site access it requires special regulations or traffic management.

This work will draw examples regarding the implementation of geophysical methods in urban territories and centers from Greece. The case studies will illustrate the importance of urban geophysics and archaeology in cases of private and civil construction works, new city planning, as well as in activities oriented to surveillance and analysis of regional risk assessment of monuments. Geophysical data were collected employing state of the art 3-D imaging techniques like Electrical Resistivity Tomography (ERT) and Ground Penetrating Radar (GPR). Complementary mapping methods (magnetic gradiometry, electrical resistance) were used to support and enhance the information retrieved by the imaging methods. Inversion algorithms, filtering techniques and horizontal slicing methods were used to enhance the information of the subsurface images. The resulting images, both in the form of 2-D maps or 3-D representations, depicted the location and the extent of the buried architectural relics and contributed to the guidance of the subsequent excavations.

Field campaign and data processing strategy

A systematic strategy was employed to collect the field geophysical data which was always adjusted depending on the special needs and specific requirements of each site. The 3-D ERT data were acquired with multichannel resistivity equipment along dense grids of parallel 2-D lines, employing diverse electrode configurations thus ensuring the accurate 3-D mapping of the subsurface archaeological structures. The multiple GPR reflections were recorded along parallel dense transects using 250 MHz and 450MHz antennas. The gradiometry and resistance mapping methods covered the areas in individual grids which were joined afterwards to formulate the mosaic of the investigated site.

The data were processed based on a systematic workflow. Despiking filters were used to remove noisy ERT measurements due to poor electrode contact and a 3-D inversion algorithm (PAPADOPOULOS et al. 2011) was used to reconstruct a subsurface resistivity model resembling the outline of the archaeological features. The GPR signals were enhanced through the implementation of specific filters (first peak estimation, application of AGC, de-wow and DC shift, trace-to-trace averaging filters). Two-dimensional (2-D) vertical sections or horizontal slices were extracted by the 3-D ERT and GPR rendered volumetric models. Grid and line equalization filters, selective despiking and compression of dynamic range were employed to separate the archaeological signal from background geological noise in gradiometry and resistance mapping data. The final geophysical maps were overlaid on topographic and satellite images based on ground control points that were captured through Global Positioning System (GPS) units. A Geographical Information System (GIS) platform was used to integrate, manage and interpret the geophysical data in the perspective of the archaeological importance.

Private Construction Activities

Area of Kato Poros, Herakleion, Crete

The geophysical investigations covered a section less than 260 square meters in the private property of John and Nikos Markopoulos. The site is situated close to harbor of Herakleion (Crete) on a small hill south of the seaside avenue, in a local territory know as "Kato Poros" (Fig. 1). An older facility in this area was demolished in order to construct a newer building complex. Preliminary excavations activities in the site brought to light wall sections of archaeological importance. Older rescue excavations in the broader area of "Kato Poros" have already revealed carved and cavernous graves. The GPR and the electrical resistance methods were applied in the area emphasizing the dense sampling of the site (50cm sampling and line spacing for resistance measurements; 5cm sampling space along GPR transects separated every 50 cm). The circular area (*I*) with diameter 3.5–4.0m (Fig. 2a, d) that exhibited high resistance values and increased reflectance is related to an older buried waste tank that reaches the depth of 2 m below the ground surface. The small circular (*J*) at the south east corner of the area is probably caused by a smaller and older waste tank. The southern anomalies (*G and H*) were originated by a cement slab, part of the older construction. The most interesting place from the archaeological point of view, is a zone of high resistance values with north-south orientation that is formulated through the anomalies E and F. The GPR reflections verified the previous results and outlined a distinct geometry (Fig. 2a, b, d) with dimensions of 6x4m. Some more isolated reflections (Fig. 2c, d) at the north (*A, B, C*) seem to extend to larger depths. A linear anomaly (*K*) is

outlined by the GPR measurements at the east side of the area which probably outlines a wall structure that is not related to modern construction activities.

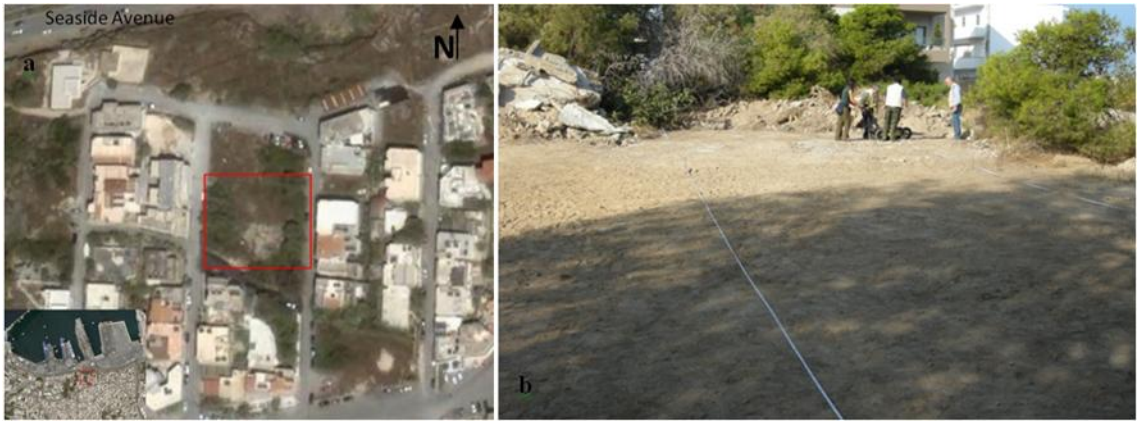

Fig. 1 – a) Quickbird satellite image from Google Earth where the investigated area in "Kato Poros" is outlined inside the red square. b) Details from the investigated site. Prior to geophysical field campaign, surface obstacles and garbage were removed from the site.

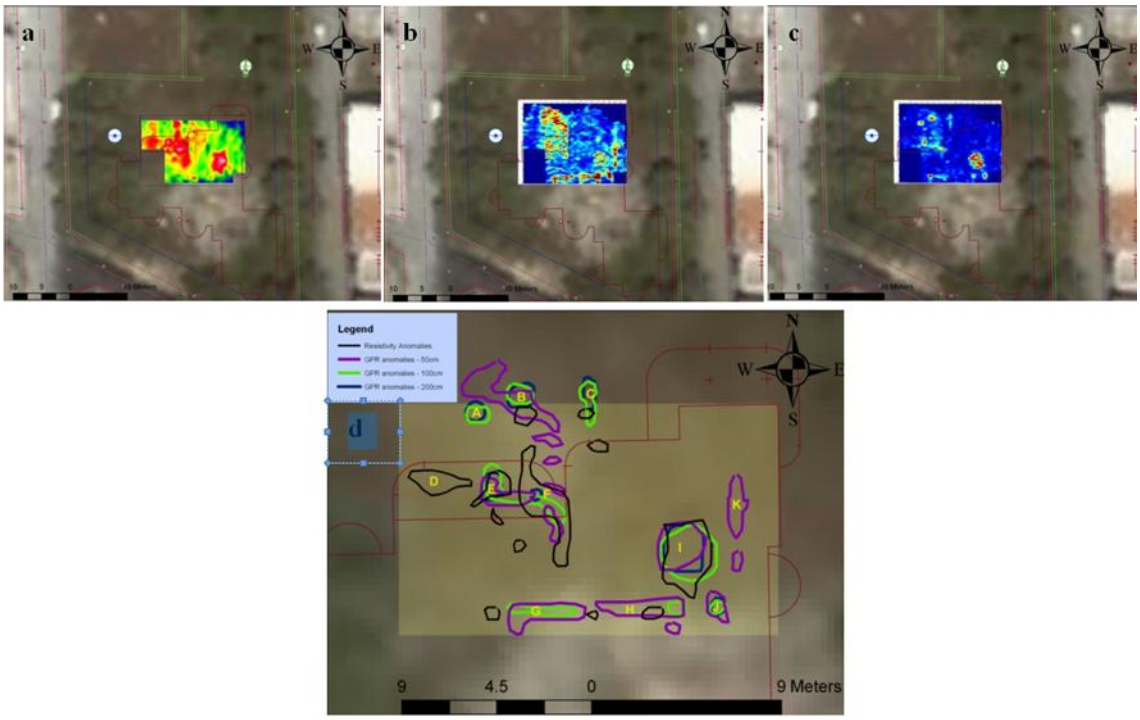

Fig. 2 – a) Final processed electrical resistance map overlaid on the satellite image. b) GPR depth slice of 50-60 cm below the ground surface. c) GPR depth slice of 100–110 cm below the ground surface. d) Combined diagrammatic interpretation of the geophysical anomalies indicated by the electrical resistance and GPR methods. – The warm and cold colors show high resistance/high reflectance and low resistance/low reflectance respectively for electrical resistance and GPR measurements.

Knossos Avenue, Herakleion, Crete

The geophysical explorations in the property of Fragiadakis (Fig. 3a, b) at Knossos Avenue, leading from Herakleion to Knossos, were seeking to evaluate the possibility of locating structures of archaeological interest in the area. This hypothesis was enhanced by the identification of a Geometric Period tomb in the

parking place of 2nd Revenue Service of Herakleion. Furthermore, the wider area in a radius of at least 300 m is known to host Early Geometric, Hellenistic and Roman cemeteries. The high resolution geophysical survey was completed in terms of ERT and GPR methods through parallel dense transects. The inter-line distance for the GPR and the ERT measurements was 0.5m and 1.0m respectively.

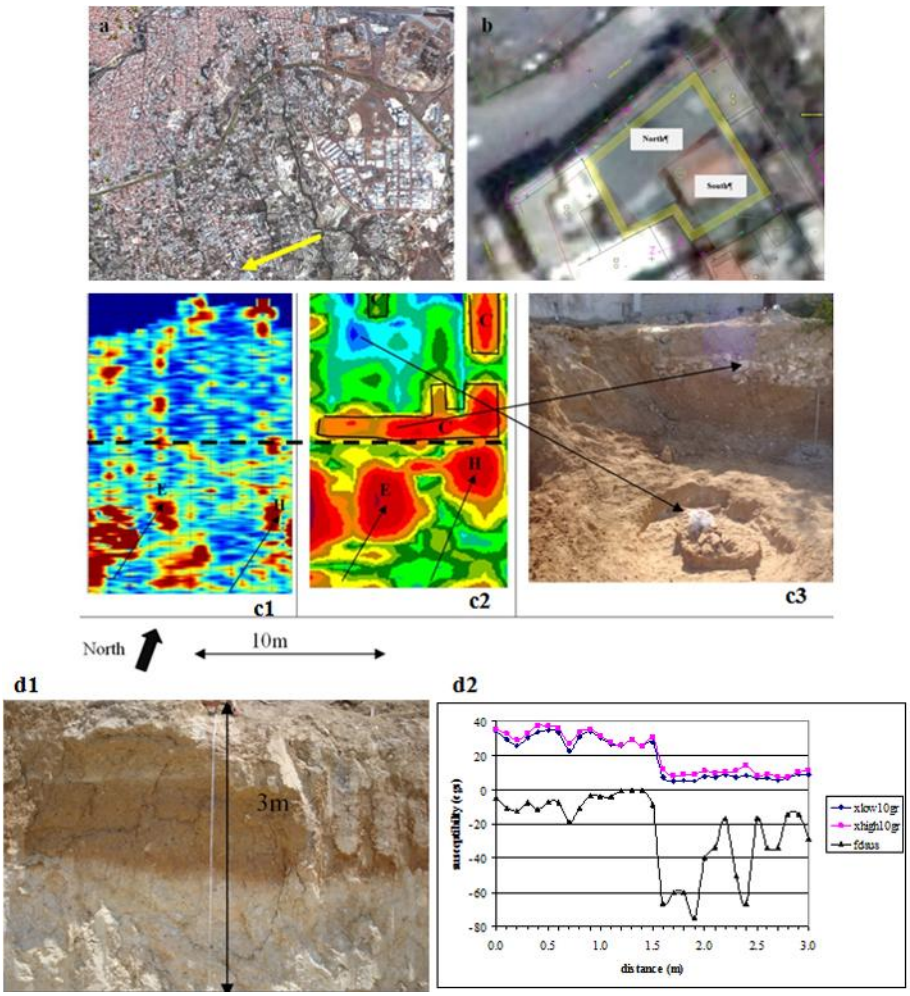

Fig. 3 – a) High resolution satellite image of Herakleion where the place of Fragiadakis property is indicated with the yellow arrow along Knossos Avenue, on the southern exit of Herakleion city to Knossos. b) The south and north sections of the property where the geophysical investigations were focused. c) GPR (c1) and ERT (c2) slice of depth 0.5m below the surface of the southern section in Fragiadakis property and excavation results (c3) from the northern half of this section. The dashed line indicates the southern boundary of the excavation trench. d) Image of the vertical section separating the northern and the southern parts of the property along which the soil samples for magnetic susceptibility measurements were collected (d1). Results of the high, low and frequency dependent soil magnetic susceptibility measurements (d2).

The southern section of the property, which has 3m elevation difference with respect to the northern part, exhibited the highest archaeological interest (Fig. 3c). Anomalies E and H appeared from the depth of 0.5m below the ground as strong reflectors and with increased resistivity values. These anomalies, which reached the depth of 1.8m, were located within the anthropogenic layer where various archaeological artifacts were recognized (e.g. ceramics, lithic tools etc). The circular low resistivity anomaly which is outlined a couple of meters to the north of a modern wall (anomaly C in resistivity map), was correlated with ceramic vessels

filled with partly saturated soil. Preliminary results indicated that this material is contemporary to the Early Geometric-Hellenistic cemetery of the broader area (ROUSAKI and ANAGNOSTAKI 2010). The magnetic susceptibility measurements that were completed in soil samples along a 3m vertical profile (Fig. 3d) clearly separated the anthropogenic layer, having a thickness of 1.5m starting from the ground surface, from the marly geological background formation.

The New building of IMS, Rethymno, Crete

The Institute for Mediterranean Studies (IMS) is hosted in a renovated building in the center of the old town of Rethymno. It comprises one of the scientific institutes the Foundation for Research and Technology Hellas (FORTH). Its expanding and increasing research activities have led IMS to invest in new building facilities. Two of the rooms of this new building exhibit significant historical importance as they were used as churches during the Venetian period. Thus an archaeological excavation inside the building was necessary prior any restoration and construction activities.

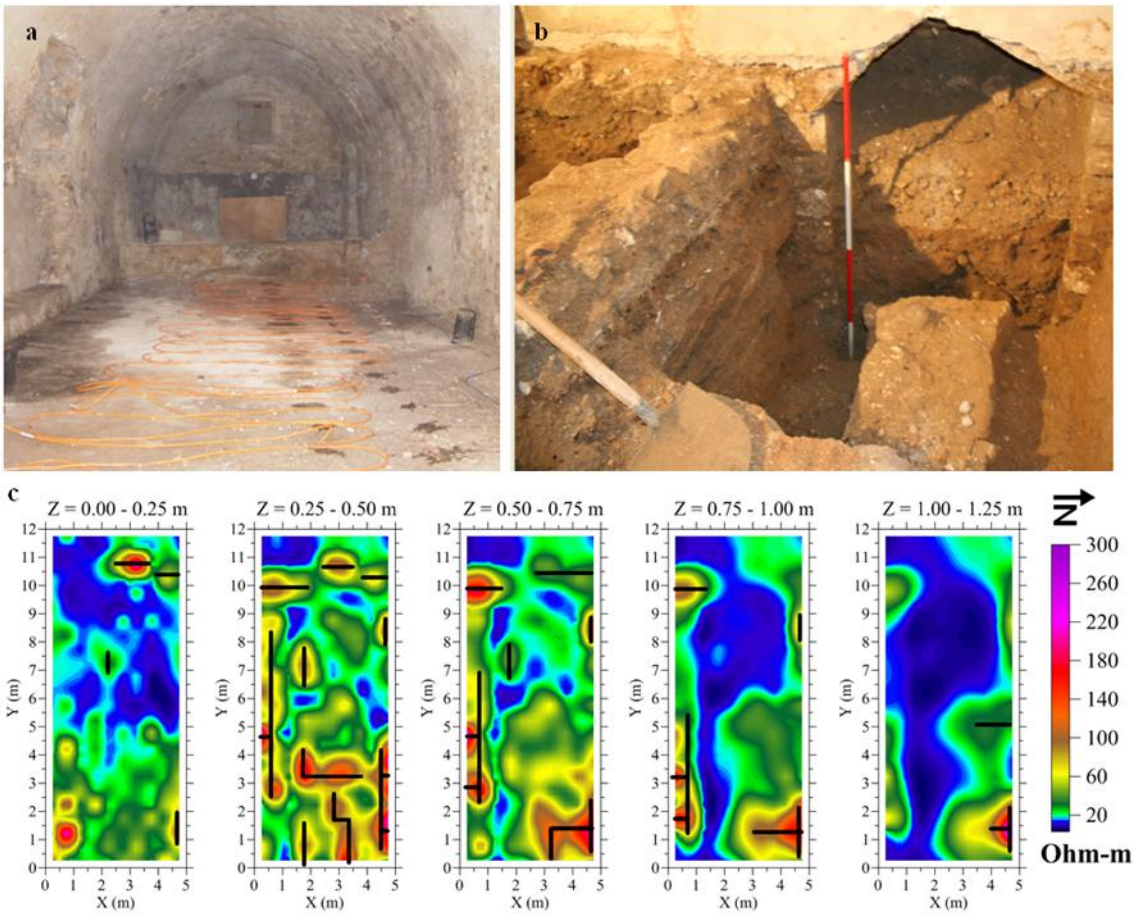

Fig. 4 – a) Investigated area inside the restorated building of IMS. b) Part of the wall that was excavated close to the entrance of room. c) 3-D resistivity inversion model (6 iterations – RMS=5.9%) in terms of depth slices of increasing depth. The diagrammatic interpretation depicts spots of high resistivity values related to wall structures.

The 3-D ERT method was employed to survey one of these rooms covering a rather small area of 5 by 12m. The electrodes were placed every 0.5m along each line and the distance between lines was 0.5m (Fig. 4a).

The dipole-dipole array was used to capture the apparent resistivity data and the maximum penetration depth didn't exceed the depth of 1.25m below the ground surface.
Areas of high resistivity anomalies were mainly concentrated at the northeast corner of the grid (X=2–5m, Y=0–5m). These anomalies were caused by buried walls that continued towards the second room that is attached to the north. A linear anomaly was also observed at the south of the room (X=0–1m, Y=3–8 m), where some vertical parts seemed to further continue to the south. Finally, some other minor linear anomalies were located at the west of the investigated area. Figure 4b shows a cooking area belonging to a house of more recent (historical) times that was revealed by the excavations followed the geophysical survey.

Civil Construction Works and New City Planning

Areas of public performance: The case of the Amphitheatre of Ierapetra (Crete)

The municipality of Ierapetra in south-east Crete (Greece) initiated a project of constructing a modern theater to accommodate its summer cultural activities. The broader area where this new theater is planned to be constructed occupies the place where the roman amphitheatre of Ierapetra was situated in the past. Onorio Belli (1550–1604), a physician and architect originated from a family of artists in Venice, gave a description of Ierapetra's amphitheatre which was constructed between two little hills or rocks. The six buttresses of solid masonry without any decoration were built at each extremity in order to complete the oval shape of the amphitheatre and the stairs were between those buttresses (FALKENER 1854). Nowadays the only valid information about the location of the amphitheatre, accompanied by a draft plan of it (Fig. 5a), is provided by British Vice-Admiral Thomas Spratt (SPRATT 1879).
The identification of possible ruins related to the amphitheatre in this area faced specific difficulties arising by the general settings of the surrounding environment, mainly due to the absence of any visible indications or ruins that could be correlated with the amphitheatre and the urbanized setting that generated sources of increased levels of noise. The implementation of GPR was very convenient as most of the 3,300 square meters area that was surveyed was flat and at the level of the main road. The GPR depth slices up to three meters below the surface indicated the almost semi-circular area *Amph1* which is oriented in the NW-SE direction (Fig. 5b, c). The shape of this area could be potentially correlated with the western part of the amphitheatre's orchestra within an error range of 5–7 meters. This error can be considered acceptable taking into account the error propagation due to the original rectification of Spratt's map on the satellite image of the area. To the east of *Amp1*, another anomalous region (*Amp2*) has been identified and could be an indication of the eastern side of the orchestra containing part of the cunei. Even if the specific area has been used as a modern industrial facility in the recent past (Minos factory for olive oil and soap production), geophysical prospection techniques were capable in identifying the deeper geophysical features that can be correlated well to the possible ruins related to the amphitheatre of Ierapetra.

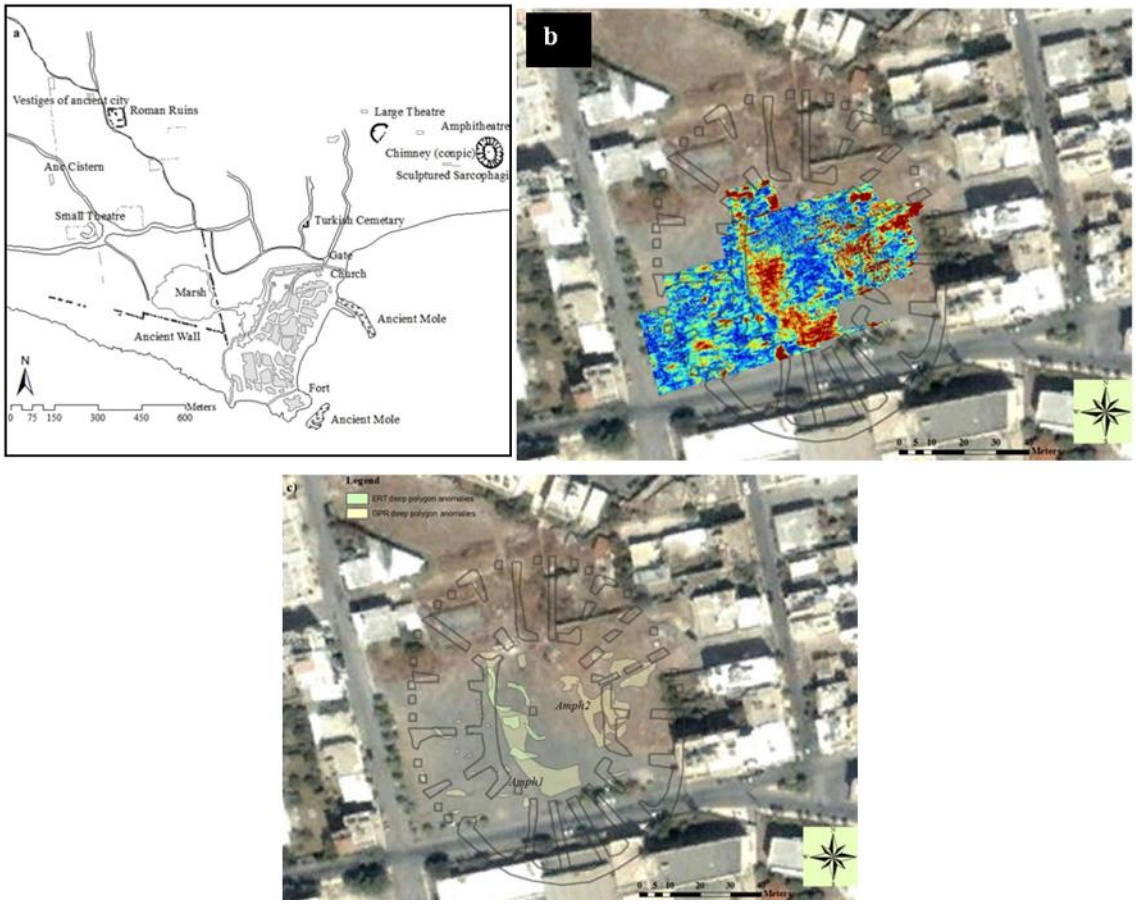

Fig. 5 – a) Reproduction of the geo-referenced and digitized Spratt's map where the location of the archaeological ruins of Ierpetra that Spratt visited are shown. b) Overlay of GPR deep depth slice (2.9–3.0m) on the satellite image of the area where the amphitheatre of Ierapetra is located. c) Diagrammatic interpretation of strong GPR reflections . The outline of the amphitheatre is also depicted.

Saint Peter's Basilica, Herakleion, Crete

During sidewalk construction work along the seaside avenue of Herakleion, a small section of a palaeochristian church was partially excavated. Due to the urgent character of construction works to restore the seaside avenue, the area was prospected using the GPR technique. The fieldwork had to be conducted during the night in order to meet special requirements for traffic management, as the area extends over a main route that leads from the port to the western exit of Herakleion city. An area of more than 2,000 m^2 was explored in systematic way. The goal was to cover as much of the area as possible, but surface obstacles like ditches, pipelines, and parked cars limited the area coverage.

Fig. 6c shows two representative GPR depth slices extracted by the GPR volumetric data. The warm colors indicate a significant number of strong reflectors in the western part the palaeochristian church. This clearly shows that the church comprises part of a broader architectural complex. The subsequent excavation in a small section of the investigated area to the south and west of the palaeochristian church revealed this architectural complex (Fig. 6c). This case study signifies the efficiency of GPR technique in the archaeological exploration of urban areas. The use of this method seems to be adequate to reconstruct the complex subsurface material properties encountered in the urban settings and to guide the archaeological excavation in selected places.

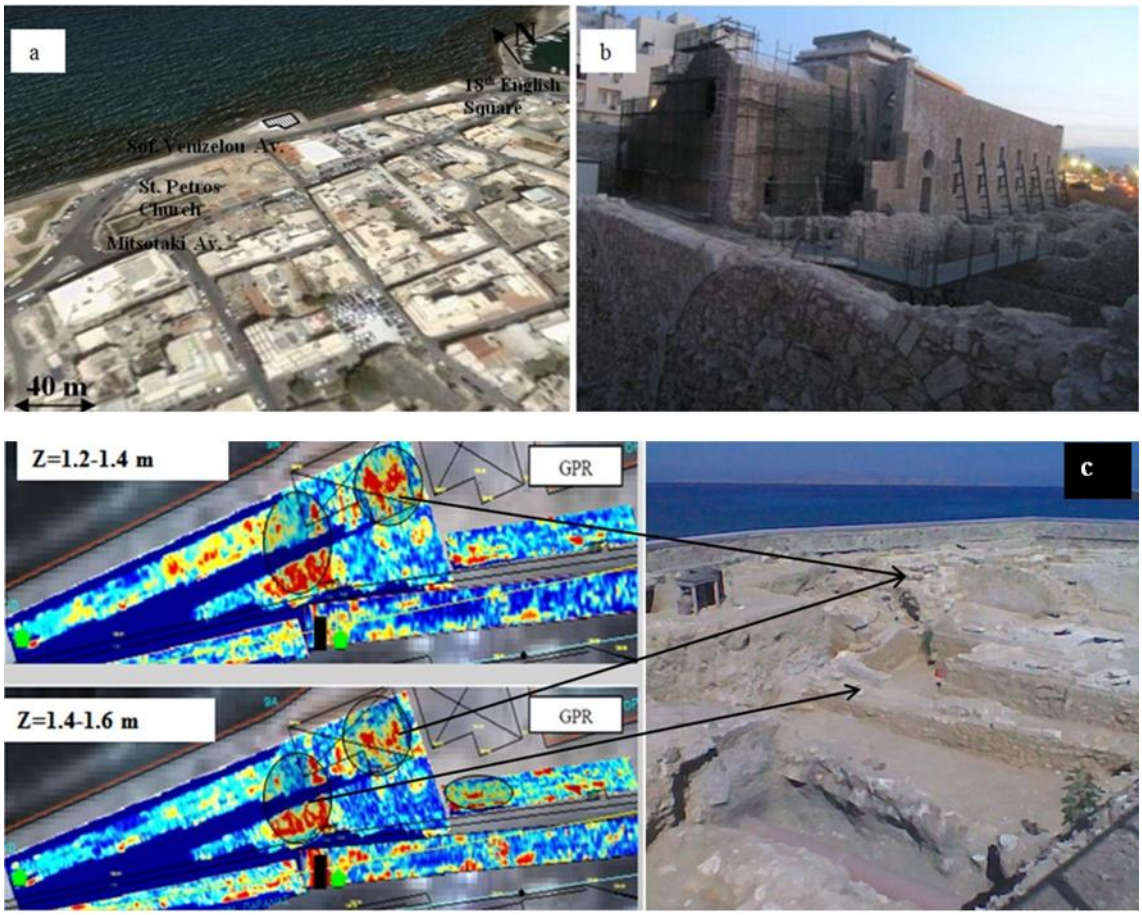

Fig. 6 – a) Panoramic view of the investigated area along the seaside avenue at the centre of Herakleion city. The dashed polygon indicate the area where the palaeochristian church was excavated. b) Recent view of the Saint Peter's church, which is located along the Sof. Venizelou Avenue and across the area of the investigations. c) Correlation of the excavated archaeological structures (right photo) with the GPR results (left photo) SW of the palaeochristian church.

Highway construction: Location of possible tombs in Volos, Thessaly

During the construction works of the new highway of Volos the rescue excavations brought to light an unknown vaulted Mycenaean tomb. In order to explore the possibility of the existence of other similar tomb(s) in the surrounding area, a geophysical campaign was organized applying electrical resistance mapping and ERT methods employing Wenner and dipole-dipole electrode configurations. The survey covered several places either in terms of parallel resistance transects forming specific grids or individual 2-D ERT imaging sections (Fig. 7).

Grids A and B were located at the East and North of the already exposed tomb. The apparent resistivity values ranged between 90 and 800 Ohm-m along the 17 transects having an inter-line distance equal to 2m. The electrode spacing along the lines was also set to 2m. At the south-west (x=20m, y=30–70m), south-east (x=2m, y=50–84m) and north (x=6–16m, y6–18m) the lateral resistivity changes of the superficial layer (up to 2m), registered with high resistivity values, came to be of geological origin (Fig.8a). Within the area covered by GRID C (Fig. 8c) the apparent resistivity values reached the maximum value of 450 Ohm-m which in combination with the shape of the anomaly registered at the south-east (x=6–18 m, y=17–29 m) indicates that this anomaly cannot be correlated with the existence of a tomb.

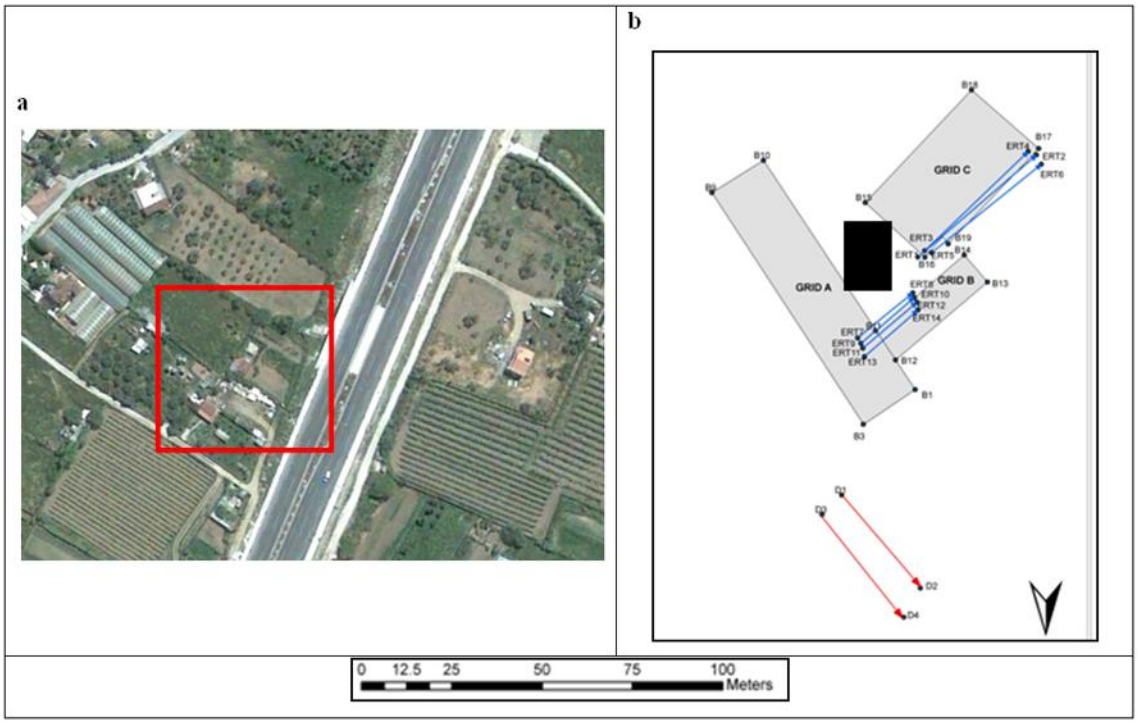

Fig. 7 – a) Recent satellite image (Google earth) of "Kazanaki" area in Volos (central Greece) where the geophysical region is outlined within the red rectangular. The new highway that was constructed after the geophysical survey is visible. b) Distribution of the ERT lines and grids that were laid out to survey the area. The black square indicates the location of the already excavated tomb.

A small section in GRIDS A, B and C was surveyed with the ERT method through the completion of four parallel transects in GRID B and three parallel lines in GRID C. The reconstructed 2-D inverted resistivity sections are shown in Fig. 9 in a quasi 3-D representation. All four lines in Fig. 9a show similar pattern and structure with the continuous existence of two ellipsoidal high resistivity anomalies marked with 1 and 2. Although the absolute resistivity values (less than 1,000 Ohm-m) could lead to the existence of a buried tomb partly filled with soil, the relatively small thickness of these anomalies (~1.5m for anomaly 1 and ~1m for anomaly 2), in combination to the diffusion of the signal in lines ERT9-10 and ERT 7-8 probably indicate the existence of a geologic layer composed of sand and gravel, thus minimizing the possibility for the location of a tomb. On the other hand the results from the three 2-D lines completed in part of the GRID C (ERT5–6, ERT1–2, ERT3–4) clearly show a stratified subsurface structure composed of three horizontal layers. The superficial layer up to ~1.5–2.0m corresponds to fine sand with resistivity values 100–400 Ohm-m, the second layer than exhibits high values of more than 400 Ohm-m is caused by the concentration of coarser material (coarse sand and gravel) and has a maximum thickness of 2–2.5m. The deeper layer with values within the range of 10–100 Ohm-m corresponds to a clayey formation with fine sands.

The overall results of the electrical resistivity survey in "Kazanaki" area indicated that the registered geophysical anomalies were of geological origin and these anomalies cannot be attributed to the existence of a buried tomb. This "negative" geophysical result proved valuable for the on-going construction activities of the new avenue and gave a clearance for the continuation of the construction works.

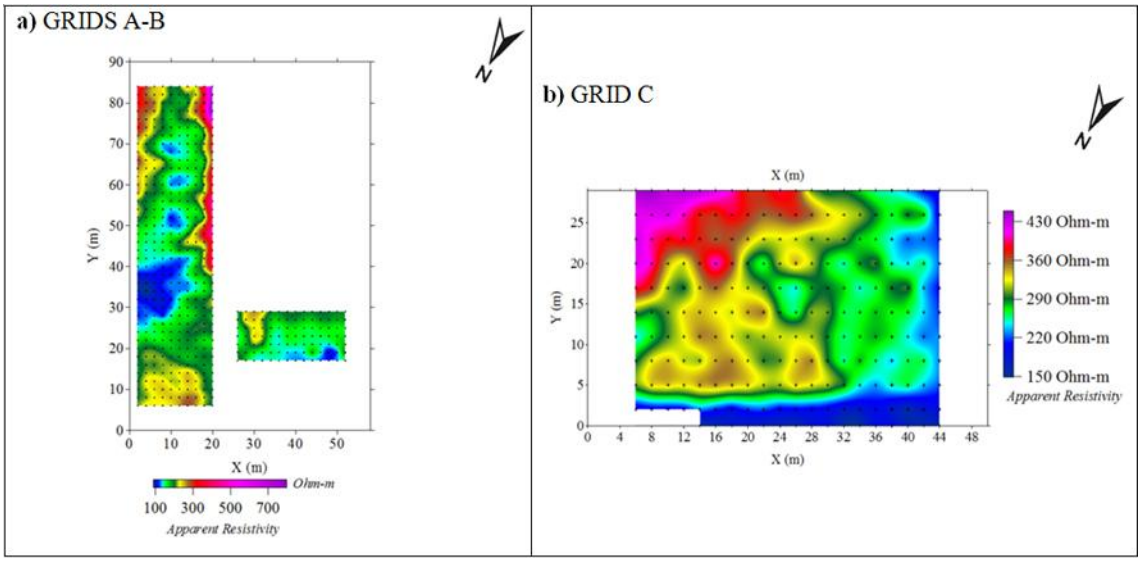

Fig. 8 – Results of the resistivity mapping of the areas covering the grids A, B (a) and C (b).

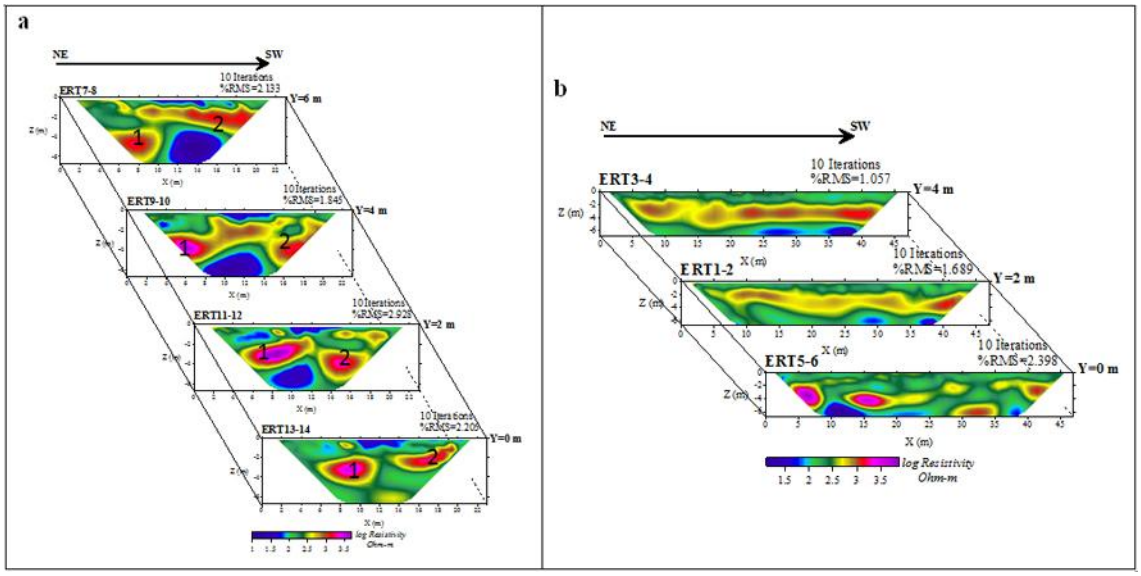

Fig. 9 – Quasi 3-D resistivity models resulted by the 2-D inversion of the ERT data collected from selected places of "Kazanaki" area.

Surveillance of Monuments

Roman Small Theatre of Ierapetra (Crete)

The modern city of Ierapetra is a relatively small town located at the south-east coast of Crete which is built over the location of ancient Ierapytna that was one of the most important towns of Crete during the ancient times (Fig. 10a). Ancient Ierapetra hosted a significant number of public buildings (e.g. a naumachia, an amphitheatre, two theatres, temples, aqueducts and thermae). Among these monuments, Onorio Belli, a past traveler of the island, has given a detailed plan of the small theatre which was in a perfect condition by the time he visited it (FALKENER 1856). The recent visible archaeological ruins are located in a fenced area at the west exit of the city and their preservation level is rather poor (Fig. 10c).

The geophysical survey covered more than 2,000 square meters with the magnetic gradiometry, GPR and ERT methods having a complete overlap with these three techniques. The ERT data were gathered along twenty three south-north parallel lines employing the pole-dipole configuration. The inter-electrode distance was one meter along all the lines while the minimum inter-line distance was 1 meter and the maximum 4 meters. The resolution of the magnetic gradiometry data was 0.5m along both directions. The GPR data were collected along parallel transects 0.5m apart, and sampling interval 5cm along the lines (Fig. 10b).
The magnetic gradiometry data exhibited high levels of background noise originated by past excavation trenches, numerous scattered metallic objects and the metallic fence to the north. In general the highly magnetic disturbed area along a south-north direction (almost 42–43m) at the west of the section was correlated with the visible archaeological ruins and the remaining material from the excavation trenches (Fig. 10f).
On the other hand, the GPR results were quite successful as a number of strong reflectors related to archaeological ruins buried up to 1.5 meters below the ground surface were revealed. Towards the north-east, a cluster of east-west aligned linear reflectors were outlined. The larger of them is 14 meters long and 3.5 meters wide and is curved towards the north. The linear anomalies at the west appear with a north-south direction. The most distinguishable of them originates from the house's yard and extends for almost 19 meters to the south. Furthermore, the GPR measurements indicated the continuation to the east of the visible ruins located at the south elevated point of the area. Finally, the isolated strong reflections at the north-west were probably caused by back-filled soil due to the past excavation works (Fig. 10d).
The results of the 3-D ERT survey indicated a series of high resistivity linear elements at the central and northern part of the area which can be attributed to superficial architectural relics. On the other hand, the disturbed areas to the west, next to the excavated trenches, were caused by back-filled material. A semi-circular structure is registered at the NW part of the area, while two isolated high resistivity anomalies with similar orientation (north-south) and dimensions (3.5x1x1 m) are shown at the central and SW section of the territory. All these anomalies represent the shallow to medium depth archaeological features buried between 1.5 and 2.5 meters below the ground (Fig. 10e).
The integrated diagrammatic interpretation of the diverse geophysical anomalies indicated that the main interest is focused on the central part of the area, where a "closed" complex of geophysical anomalies extending up to a maximum depth of 3m below the ground is outlined. A second priority area was distinguished at the SW section of the region where the linear anomalies are probably related to other architectural structures. To this stage an effort was made to rectify Belli's plan for the small theatre on the satellite image in order to correlate it with the geophysical anomalies. The problem was approached by a trial and error methodology by testing different rectification models trying to correlate every time different parts of the theatre from Belli's plan with the visible ruins and the geophysical anomalies. The rectification was based on a first order polynomial (affine) transformation resulting an error of less than 50cm. The most successful effort is illustrated in Fig. 10g that resulted in a diameter for the koilon and the orchestra of 60 and 27 meters respectively which is in a very good agreement with the true dimensions of Belli's plan. Another important aspect is the eastern orientation of the theatre which again is in agreement with Belli's descriptions.

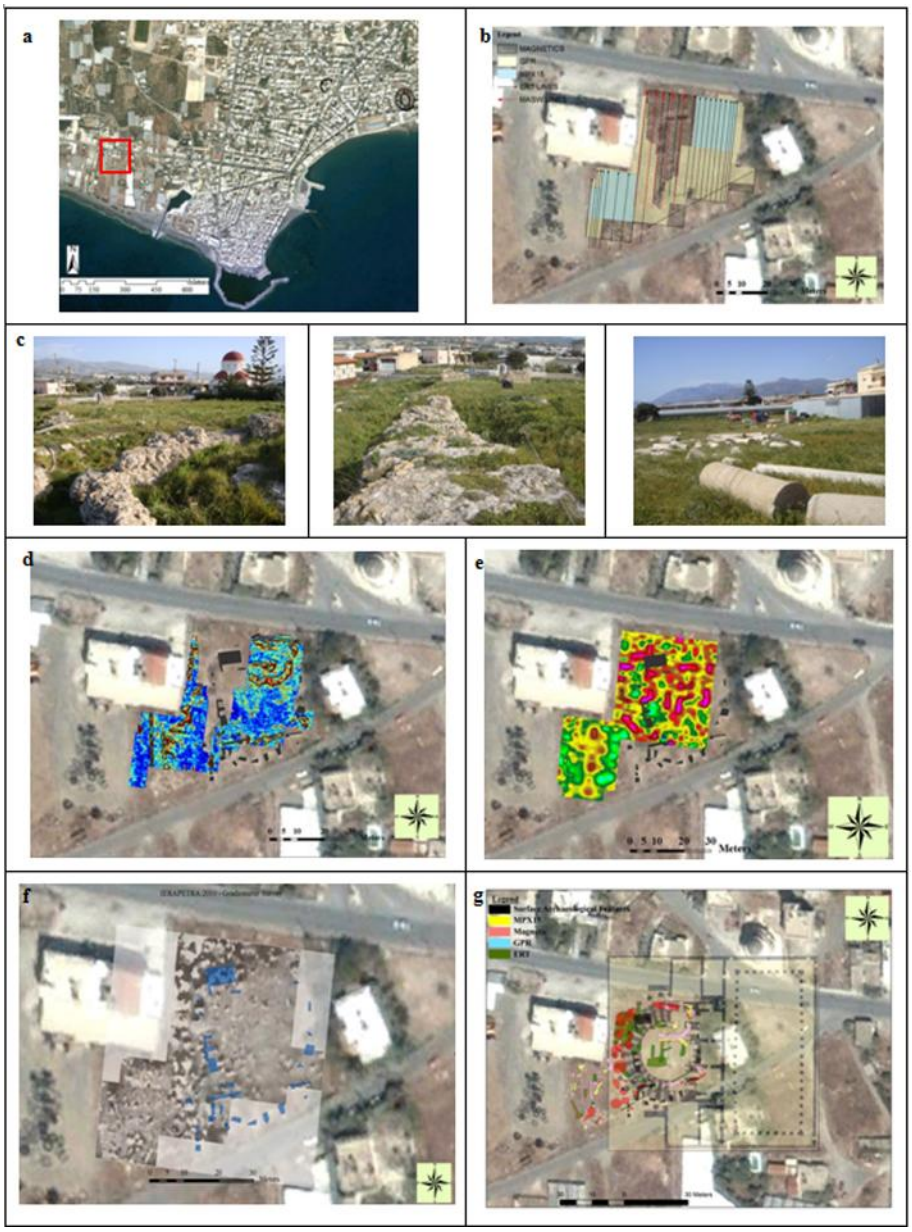

Fig. 10 – a) Satellite image of the wider area of Ierapetra (Google Earth) where the location of the small theatre is outlined within the red rectangular. b) Zoom in of the investigated area along with the coverage of the integrated geophysical methods used to survey the site. c) Views of the archaeological site and the visible remains of the small Roman theatre. d) Rectification of the GPR slice on the satellite image corresponding to 1.2 meters depth below the ground surface along with the diagrammatic interpretation of the strong reflectors. e) Representation of ERT depth slice of 1.0 meter on the satellite image. f) Magnetic gradiometry results. g) Integrated diagrammatic interpretation of the geophysical anomalies. The geophysical anomalies were superimposed on the satellite image of the area and on a rectified image of Belli's plan indicating the most probable orientation of the ancient theatre.

Acropolis of Athens

The Acropolis hill is the most important site of Athens and probably one the most important archaeological site worldwide. It is situated on a precipitous hill 160m above sea level and the site was already occupied in the 17th century B.C., and took its final shape during the 5th century B.C. (Golden Era). It hosts masterpieces of Ancient Greek architecture such as the Parthenon and is surrounded by a thick wall with thickness up to 5m. The south Acropolis wall has been built at the beginning of the Golden Era and since

then it withstood several additions. It has been distorted due to the presence of fill behind it, while further areas of increased moisture threaten the integrity of the construction. As part of an extended conservation and restoration project of the circuit walls of the Acropolis undertaken by the Acropolis Restoration Service, the application of ERT geophysical technique was considered useful for gaining a better insight of the structure of the south Acropolis wall. The project was undertaken by the Aristotle University of Thessaloniki with the support of the Lab of IMS-FORTH.

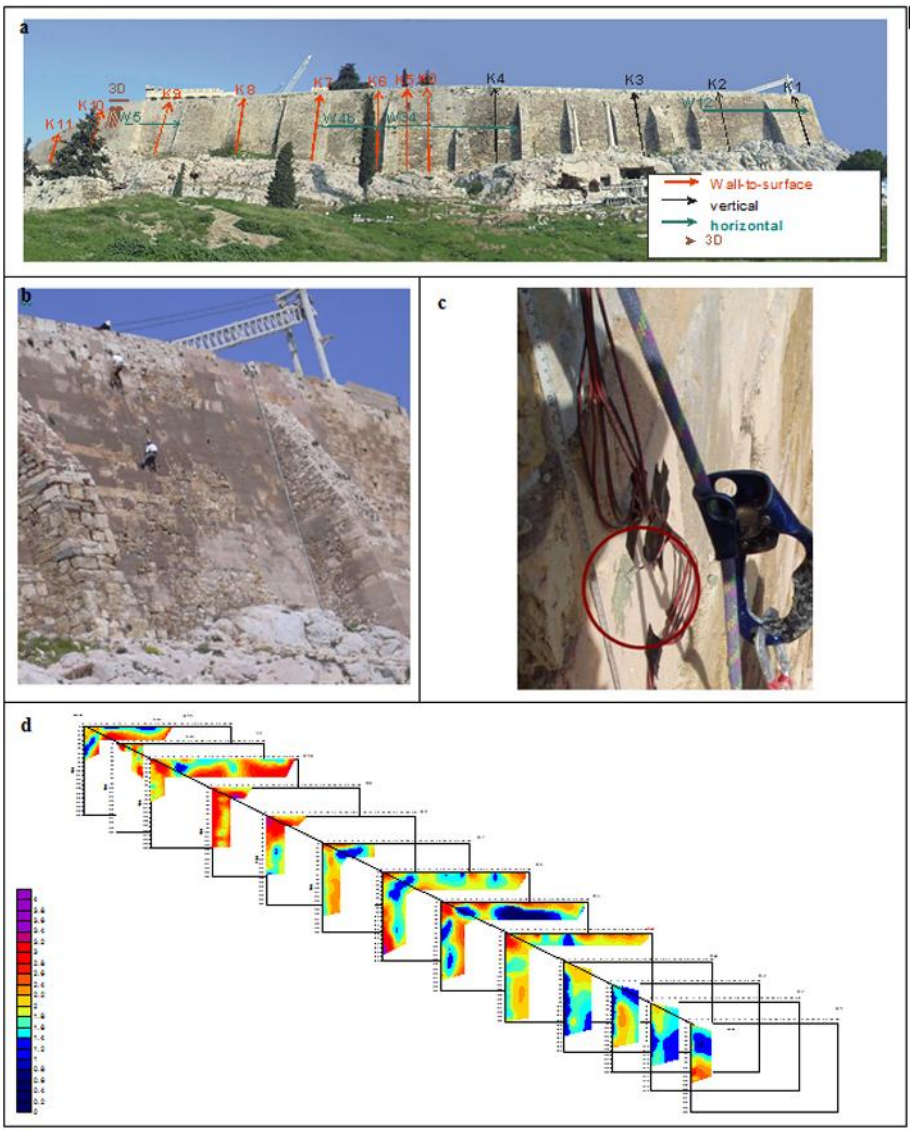

Fig. 11 – a) View of the south wall of Acropolis where the location of the different ERT sections is outlined. b) Fitting of the cable and the electrodes on the surface of the wall by the climbers. c) View of the bentonite electrodes attached on the wall. d) Resistivity reconstructed models of the ERT lines from west to east (Figures taken from TSOURLOS and TSOKAS 2011).

A modified field strategy was adjusted to the special requirements for the geophysical survey of this standing monument. A number of 2-D ERT sections were gathered employing diverse measuring modes: on the surface of the hill, vertical and horizontal on the surface of the wall and wall-to-surface (Fig. 11a). The multinode cable was placed on the wall surface with the help of two climbers (Fig. 11b). The injection of the

current and the measuring of associated potentials was accomplished through "contact" electrodes made of wet bentonite that were placed on the surface of the wall (Fig. 11c). The accurate electrode positioning (every 1m) on the wall was made with the aid of a total station. The apparent resistivity data were gathered with the Wenner-Schlumberger or dipole-dipole configurations exhibiting the collection of high quality data with relatively low contact resistances (less than 2 KOhms).

Standard 2-D inversion software (TSOURLOS 1995) was used to reconstruct the subsurface resistivity. The algorithm was further modified to account for the wall-to-surface measurements by assigning a very large resistivity value (10^9 Ohm-m) to the finite element mesh to simulate the effect of the air on the wall electrodes (TSOURLOS and TSOKAS 2011). In Fig. 11d the inversion results from all lines involving electrodes placed vertically on the wall are depicted from west to east. It becomes clear that the whole eastern corner of the wall exhibits relatively low resistivity values showing increased moisture content. This situation is caused by the existence of the old Acropolis museum it is situated behind the wall. Thus the drainage system of the old museum is considered responsible for this increased moisture content. The central section also shows low resistivity values. The relatively dried conditions on the wall surface and in the internal part of it are suggested by higher resistivity values registered on the western ERT sections. Further it was possible to assess the thickness of the wall in specific sections through the high resistivity values.

The Mycenaean cemetery at Kolonaki, Theves, Boeotia

The Mycenaean cemetery in the region of Kolonaki at Thebes consists of cavernal or carved tombs, many of which have been excavated in the past. Their exact location however remains unknown, but it has been recorded in the past that they exist in clusters. The mapping of the area was conducted through soil resistance and GPR measurements, as the rest of the techniques would have faced extreme difficulties due to the existence of modern interventions in the area and the existence of modern building around the site (Fig. 12). The site imposed even more difficulties since there were also a number of beehives located within the site.

Soil resistance measurements made use of the Twin probe array and soil resistance anomalies reached the value of 21 Ohms. High pass filtering was employed to isolated areas having increased resistance values. Depth slices of 10cm and 25cm were created for depicting the intense GPR reflectors. The processing of the data indicated that regions exhibited high soil resistance could be correlated well with the high intensity GPR reflectors (Fig. 12 c, d). These areas were indeed concentrated in clusters and their depth was varied depending on the various locations. Past excavation trenches were also identified and were excluded from the identification of the potential targets. It became apparent however that the combination of the two methods was effective in indicating the candidate location of the tombs extending over the rough terrain of the sloping hill of Agia Anna.

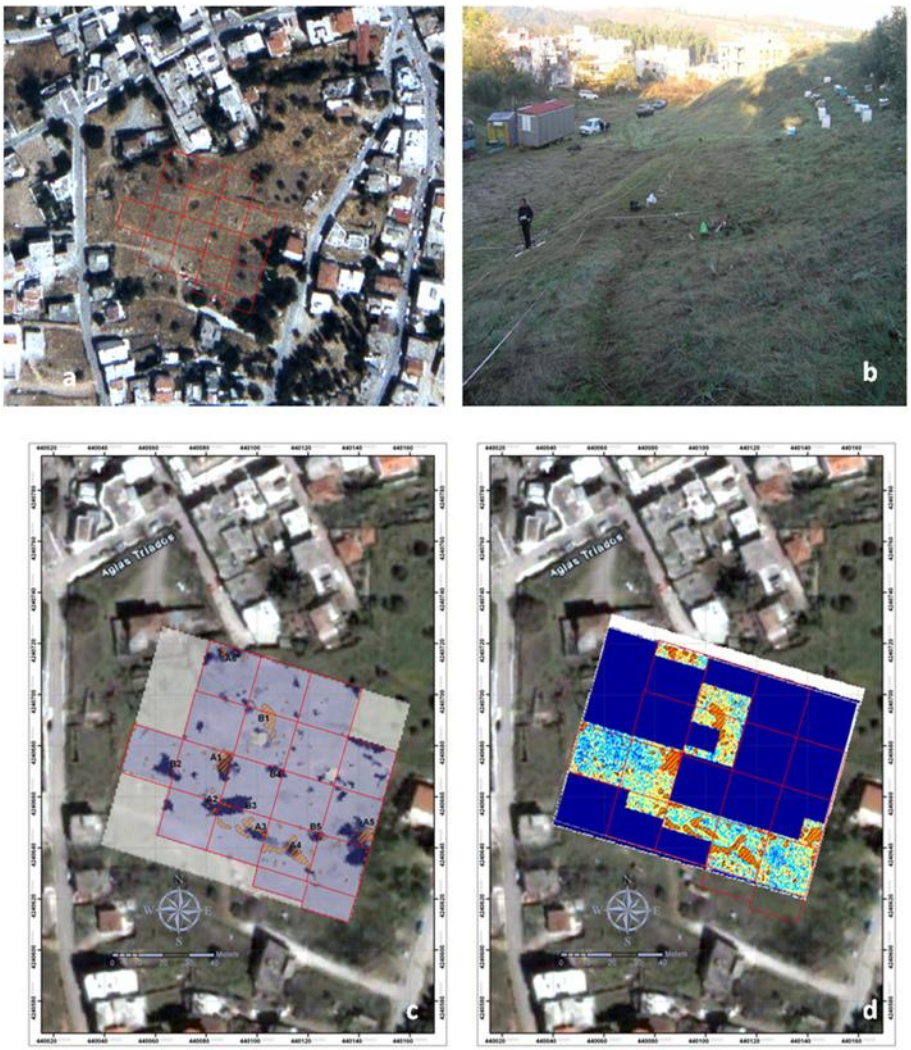

Fig. 12 – a) Layout of the geophysical grids on the Google Earth satellite image of the surveyed area located to the south of the city of Theves. b) Details of the cemetery which expands over a very rough sloping terrain, c) Overlay of the high GPR reflectors on the high resistance values, d) Diagrammatic representation of the intense GPR reflectors.

Cultural Risk Assessment Modelling

Earthquake Vulnerability and Seismic Risk Assessment in Historical Urban Areas

In the context of urban centers, seismic vulnerability analysis is mainly focused in the type of structural, geological and spatial information of buildings in direct relation to potential damages in case of a seismic episode (SARRIS et al. 2010). There are various approaches that address the earthquake vulnerability and seismic risk and most of them make use of the GIS spatial tools in correlation to the structural parameters and the geological conditions. GIS-based tools, such as HAZUS (1999) and RADIUS (2000) approach the seismic risk assessment through either generalized expert information or localized observations. Such kind of detailed information (detailed inventories, studies of structural integrity, detailed geomorphologic and tectonic studies, a.o.) does not exist for most places of the Mediterranean, where a number of archaeological monuments and historical buildings exist in a number of urban centers.

Based on the approaches of the Interreg III SeRisk project (Advanced Techniques for Seismic Risk Reduction in Mediterranean Archipelago Regions) an integrated GIS based approach was developed to approach the seismic vulnerability by considering the geomorphologic/geological characteristics and the structural parameters of the buildings. Except the obvious contribution of the topographic, geological and statistical/cadastral data, emphasis was also given to the geophysical approaches which were employed to verify and refine the geological and shallow depth tectonic regime of the urban centers. In order to collect the necessary information, electrical tomography, seismic refraction and micro noise (horizontal to vertical spectral ratio (HVSR) for the classification of geological structures in terms of the estimated amplification factor) measurements were carried out in the 3 main cities of Crete (Chania, Rethymno and Herakleio). The importance of the contribution of the geophysical techniques has to be emphasized due to the lack of detailed geological information. HVSR measurements provided a classification of geological structures, which was confirmed by the spectral analysis of surface waves (SASW). The electrical resistivity tomography was further verified the underground stratigraphy, distinguishing among the upper anthropogenic layers and the quaternary and sandy deposits.

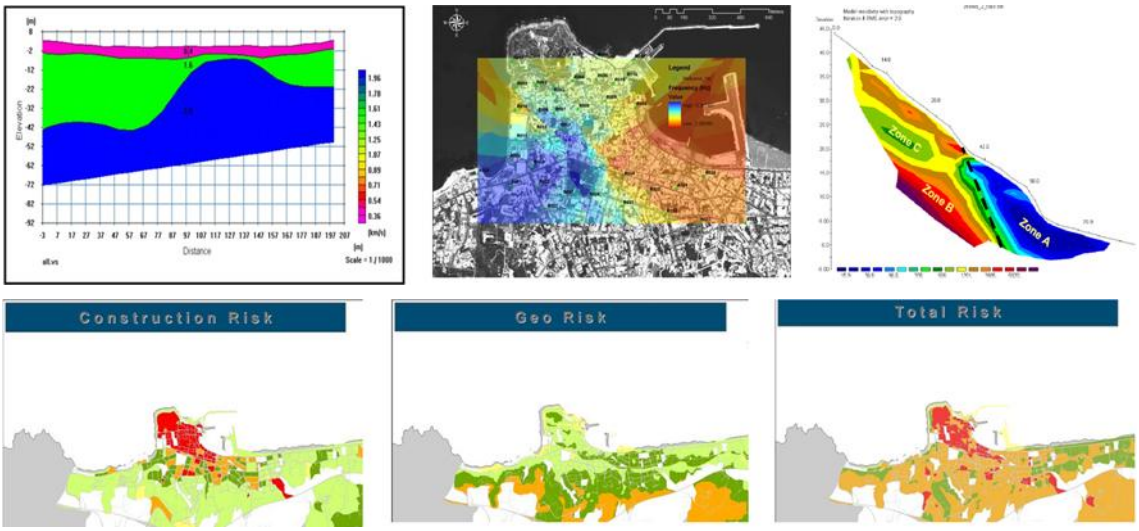

Fig. 13 – a) Indicative results from the seismic survey modeling (SASW) (left), the horizontal to vertical spectral ratio (HVSR) (center) and the electrical tomography model (right). b) Vulnerability risk for the wider city of Rethymno: construction risk (left), geological risk (center) and total seismic vulnerability risk (TSVR) (right). The red colors in the vulnerability maps indicate the higher risk. The historical Venetian center of the Rethymno extends over the high vulnerability risk area.

Vulnerability indices were created through a synthesis of the above data using multiple weighted evaluation criteria. Two main categories were formed which were ultimately joined together to produce the total seismic vulnerability index (TSVI). The geological risk took into account the geological formations, the proximity to faults, the morphology of the terrain and the past seismic activity in the region. The construction/anthropogenic risk took into account information regarding the construction year, the construction material, the number of floors, the density of adjacent buildings and other similar factors. Each one of the categories of the particular variables contributed to the final modeling with a specific rating factor, whereas a specific weight factor was imposed for each variable. From the final results of this modular approach it is obvious that the structural properties of the buildings within the historical centers (Fig. 13b for

the case of Rethymno) make them susceptible to the seismic risk. Attenuated by the coastal geological regime, the historical centers of all three cities seems to have the highest seismic vulnerability risk.

Final Remarks

In this work multiple case studies emphasizing the application of diverse and integrated geophysical methods in urban territories were presented. Generally these case studies can be regarded as successful as far as the objectives and the final results of all the geophysical surveys concerned. Geophysical techniques can indeed provide a tool for uncovering the past of the modern urban environments. They can be used for mapping private properties, analyzing the subsurface strata, guiding construction works, examine the stability and integrity of buildings/monuments and assessing the regional risk. Although the contribution of urban geophysical exploration is very significant at the stages of designing and developing modern urban infrastructures, still extremely caution has to be focused on the methodologies applied, the type of collected data and the interpretation procedure. Thus it is obvious that optimum results could be accomplished though a multilevel perspective and strong synergy between the geophysical and archaeological teams.

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Large scaled area LIDAR-data analysis at the example of Styria

Susanne TIEFENGRABER

Abstract: The large scaled analysis of the currently available LIDAR-scans of GIS Styria in combination with the archaeological site register of the federal monuments office Styria and surveys change the view of the archaeological landscape of Styria. The method offers a valuable instrument to detect new find spots and to clear the position and the dimension of already known sites. Apart from that it is necessary to make surveys to acquire an impression of how the terrain structures look like in nature and to get an experience as to what patterns on the ALS-pictures are relevant for archaeology. Furthermore it will be successful to check aerial photos, the topographic situation, old maps and cadastres. Until now in this way a big amount of new archaeological sites have been detected especially in the wooden areas of Styria. Following surveys verified and classified the features and ceramic shards provided the proof for their evidence. In addition they give an indication for the dating. The detected prehistoric hilltop-settlements in Upper Styria are marked with pronounced terraces. In the south regions of the province one can see a lot of burial mounds. Some of them are very hard to detect if they are situated in an agricultural area. When they are located in the woods they are quite visible. Moreover in most cases the structures of medieval strong holds and other fortifications can be easily identified.

Keywords: LIDAR-scans, Styria, survey, landscape use, archaeological heritage.

This contribution presents a part of my work with the currently available ALS-data of GIS Styria which is supported by Styrian federal monuments office (BDA Landeskonservatorat für Steiermark) and GIS-Styria (Stabsstelle Geoinformation der Abteilungsgruppe Landesbaudirektion).
The data from remote sensing “…have proven to be an invaluable tool for the allied subject of cultural resource research and interpretation, in particular archaeological analysis, which is closely connected to cultural heritage conservation” (STUBBS and McKEE 2007: 523).
The ALS-data of GIS-Styria is the first part of my data-fundament under examination. The second part is the information about archaeological sites and finds and the archaeological data-base at the Styrian federal monuments office (BDA). Furthermore I carry out surveys to verify the surface structures in nature. These basics were analyzed in a next step to get a new view of the archaeological landscape of Styria.
Some of the results show differences of their location and their dimension. For example that is to assert in the area around Mayerdorf, Hitzendorf and Attendorf located westerly to Graz. At the back of the north-south spreading hills of this district, called “Mitterriegel”, runs an old way. On either side of this route are several burial mounds. One encounters the same situation on the other side hill easterly. It is obvious that we can get the context of these cultural landscapes used especially in roman times in its full dimension only by the method of remote sensing. Apart from that further archaeological methods are necessary like surveying and excavation to find the places where the appropriate settlements are situated, seeing as in the flat regions, where people have been farming for centuries it is hardly possible to detect terrain structures of ancient settlements with ALS.

Furthermore the LIDAR pictures afford the possibility to detect some changes formed by cultivation of land. The recently existing tumuli in Mantscha are situated in the woods and a clear borderline detaches this area from the piece of land in the south which is now cultivated. There aren't any visible structures of burial mounds today. "The majority of crop mark sites are unlikely to have any other significant surface expression of the buried features and so LIDAR height data will not be able to identify them" (CRUTCHLEY 2010: 19). Apart from that there is a large number of identified sites which were unknown before. With the large scalded LIDAR-data-analyses one has an excellent medium for detection and protection of terrain-monuments. Although the quality of the ALS-data of GIS-Styria is not aligned for archaeological purposes there is a large quantity of terrain-monuments visible. However the number of relevant structures in variable types of country-sides differ from one another. In the flat regions in the basins of Graz and Leibnitz, the south parts of Styria, up to the border of Slovenia, the southwest and southeast parts of Styria the results are very exact. Especially in the forrest parts on the hills and slight elevations there are an array of explicitly visible find spots. "Vegetation protects archaeological remains to a certain degree from erosion. Therefore, in forested areas, archaeological sites often survive in relief and can be detected and mapped on the ground" (DONEUS and BRIESE 2011).

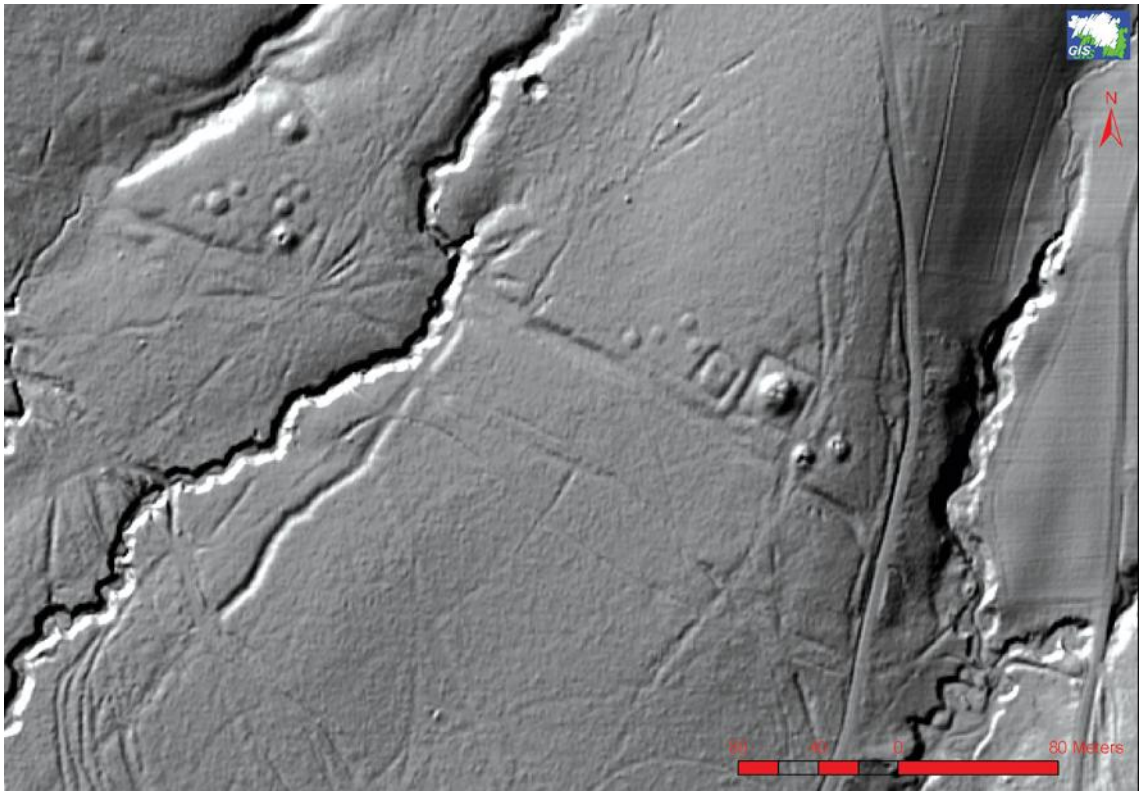

Fig. 1 – LIDAR-scan of burial mounds in Attendorf near Graz (@ GIS Steiermark).

One example would be the burial mounds in the commune of Attendorf close to Graz. A part of them is under monument protection. The biggest of these burial mounds has a 26 meter diameter and isof about three meters high. Furthermore a moat construction with an entrance in the southwest encircled it. Directly western is the next smaller burial mound with a moat construction around it. Four more tumuli are arranged western

and two eastern beside a hollow way. Nearly all of them have a hole on the top, they are bereft. But some of the other visible burrow groups nearby were not known before. Moreover it is recognizable that the tumuli are built along an old route that leads from east to west.

You can only detect this coherence by remote sensing with ALS because the whole area is covered with trees. Even if you are on location you are not in either case able to recognize the connections between the separate find-spots. “The development of full waveform LIDAR is enabling much more accurate recoding of ground surfaces within wooded and other heavily vegetated environments” (CRUTCHLEY 2010: 37).

The medieval remains of a motte with bailey at the so called “Taborkogel” are situated in the district of Deutschlandsberg at the northern border of Sulm valley. The hilltop is encircled with a ditch. In the north-western part there is a round hill which is encircled as well. Furthermore in the southern zone there is a bigger areal also with a ditch around. One can recognize some ways up the hill into the fortification. In the year 1994 an excavation by D. Kramer, Universalmuseum (former Landesmuseum) Joanneum, provides some leavings of wooden buildings with fundaments made by stone. Moreover in the surface of the terrain you can see a hole which was a cistern. Beside of documents the artificial remains prove that the fortified construction existed in the 14th and 15th century (KRAMER 1995: 73).

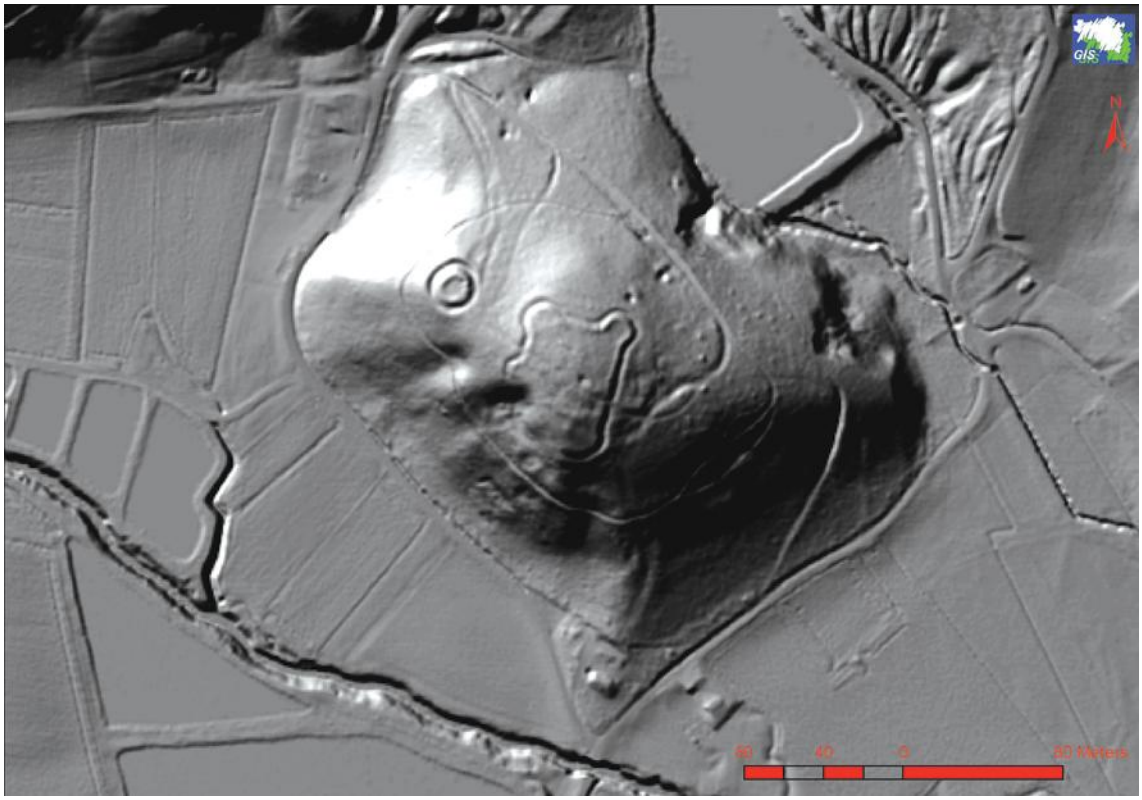

Fig. 2 – LIDAR-scan of the medieval motte with bailey “Taborkogel” near Deutschlandsberg (@ GIS Steiermark).

Also around the wider parts of the Mur-river valley in Aichfeld in upper Styria one can see a large number of archaeological terrain-monuments. Some surface structures near Flatschach close to Knittelfeld were detected in the ALS-pictures. There is a row of pits situated in a trench on the wooded hillside. At first I was not sure that they could be interesting for archaeology but a survey shows that they are marks of mining. In

this area copper, gold, silver, iron and arsenic mining has been documented since the 15th century (JARLOWSKY 1951). Some ceramic shards found in 1982 in the Flatschach trough had been classified as roman, medieval and new-age (Universalmuseum Joanneum, register of sites). Therefore it seems possible that the mining area was used before there were written records.

Moreover 200 meters south of these mining marks I detected a settlement place at the ALS-pictures. Some settlement terraces and artificial steep slopes are visible in the south, east and north. Also there is a circular ditch surrounding the settlement apart from the south side. In the northern part you can see an elevation – probably a medieval strong hold. In addition I found some ceramic dated to the Hallstatt-time and to the middle-ages. At the west-side of the settlement is a row of little pumps, these are also leftovers of mining.

Another prehistoric settlement and a medieval strong hold are situated at the northern border of Aichfeld at the top of the mountain “Zuckenhut” 750 meter high. The ALS pictures show the widespread terraces of the prehistoric settlement situated at the east, south and north side of this elevation. Moreover in the western part of the hill one can see a medieval strong hold with a ditch and a rampart on its western side. Some Hallstatt ceramic finds from the survey prove this.

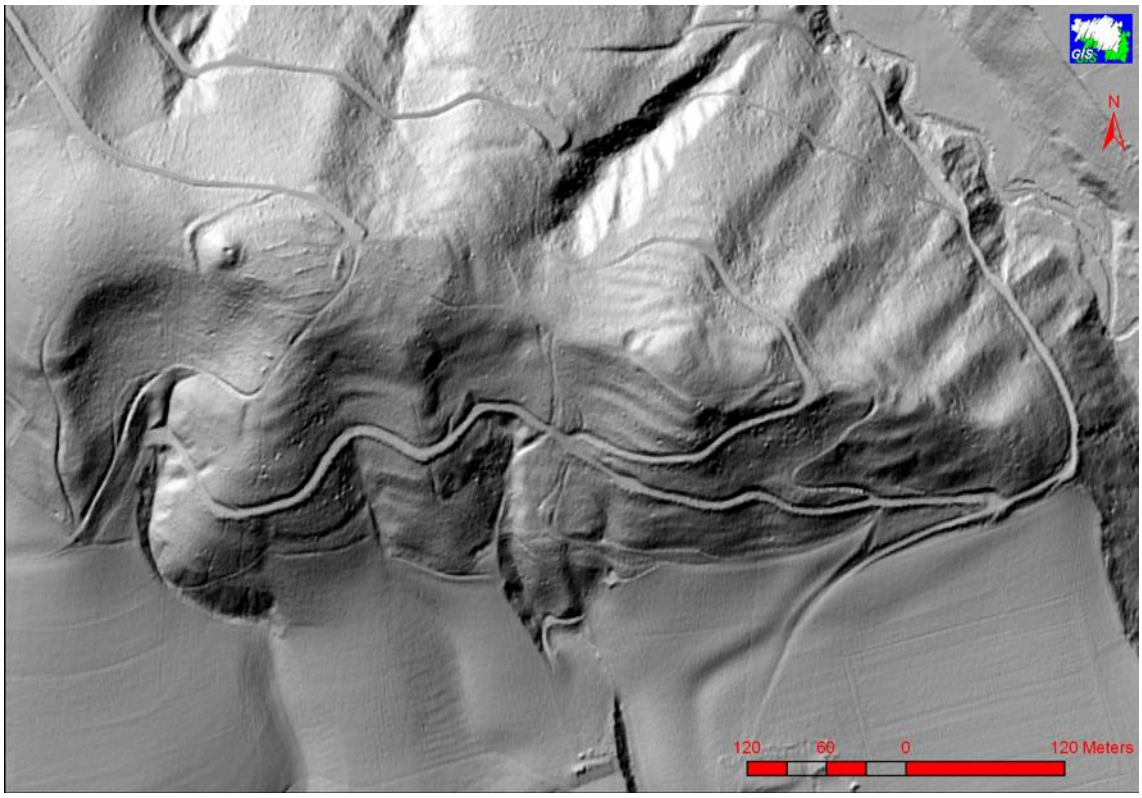

Fig. 3 – LIDAR-scan of the prehistoric settlement and medieval strong hold Zuckenhut near Knittelfeld (@ GIS Steiermark).

Another medieval strong hold lies also at the northern border of Aichfeld at the hilltop Sulzberg. This complex consists of two strong hold hills. One of them was partly destroyed a short time ago by a forest road. At this place I found some medieval ceramic fragments. “A common need in archaeology is for objects and events of interests to be dated, so that they can be arranged in the correct temporal sequence” (ROBERTS and JACOBS 2008: 347).

At the eastern end of Aichfeld there is the prehistoric settlement Schlosskogel which has a good strategic position at this narrow part of the Mur-valley. Apart from that this site has been known for several years. Some finds like ceramics and a pin from Urnfield culture prove this (BDA Styria, register of sites). But the whole dimension was not known until now. There are artificial terraces around the split top of Schlosskogel and at the gradation of the westerly elevation is a pit.

Above the farmstead “Guggamoar”, at the southern border of Aichfeld, further prehistoric settlements are located at two very steep hilltops. These small areas are very difficult for people to use. But around the hilltop artificial terraces have been created to have enough room for the construction of houses. In one of these places we found waddle and daub from ancient buildings and Bronze-Age ceramics.

The medieval motte called “Umadum” is located a short ways away from the southern border of Aichfeld in the commune of Rachau on the top of a hill about 970 meters high. The artificial terrestrial structures become very apparent in the ALS-pictures. Two ditches with ramparts surround the complex. Also in nature the structures are visible very clearly though disturbed by dens (LUKAS 2002: 76 f.).

The well known medieval castle of Eppenstein (BARAVALLE 1961: 246 ff.) and the further fortifications are situated next to an old walkway in the southward direction at the western border of a valley in the south of Weißkirchen. The fortification with a ditch and rampart is located not far at the west side of the medieval castle. Also not only medieval artefacts are known from this find spot. In this area there are finds from the Neolithic, Urnfield culture, roman period, 5th and 6th century A. D. (BDA Styria, register of sites).

The Hallstatt–settlement of Falkenberg is situated at the western rim of Aichfeld at the southern part of a narrow mountain spreading northwest-southeast. This hilltop-settlement spreads over a distance from about 1,5 kilometres. The whole settled area covers nearly 40 hectares. The excavations from 2006 to 2011 proved the dating from the 8th to the 6th century B. C. Furthermore we detected remains of more than 20 buildings in different construction techniques. This settlement belongs to the famous royal tumulus of Strettweg with its well known “Kultwagen” (EGG 1996). As well as the other mentioned prehistoric settlements around Aichfeld, Falkenberg is also unfortified (TIEFENGRABER and TIEFENGRABER 2009). About 300 metres northwest from the researched area there are more settlement terraces visible at the LIDAR-scans. Surveys at this area make it sure that the terrain structures are artificial although it was not able to detect any finds till now.

Situated westerly outside Aichfeld at the northern border of the Mur-valley there is another prehistoric settlement called “Gerschkogel”. Also at this high-lying hilltop settlement the ALS-pictures show artificial terraces. From this place various finds from several periods are known. Ceramics from the Bronze age, Hallstatt-period, Latène-period, roman-age, late roman period and middle ages were found (BDA Styria, register of sites).

Near the farmstead „Hartleb“, at the northern border of Aichfeld there is another prehistoric settlement. At a rectangular flat at the top of the hill artificial structures are distinctly visible. Two stoneaxes from the neolithic period or copper-ages are known from this place (They were shown by the owners of the farmstead).

The well known find spot “Kirchbichl“ is situated submontane at an elevation at the northern rim of Aichfeld. Unlike to the other mentioned places, the settlement of “Kirchbichl“ is not situated in the forest. Therefore the terraces show destruction by erosion and agricultural use. Although many finds have been known for long time from this area. The terraces are remains of a roman “vicus” or of a “mansio”, which was already proved

by small scaled excavations some thirty years ago. Besides these roman finds there are several older artefacts from Copper- and Bronze-age and also from Latène-period (HEBERT et al. 1997: 193 ff.). Several of the terrain structures detected by the LIDAR-data were not relatable at first. Even if you make a survey you cannot understand the meaning of them. One of these is in the wood on a slightly sloping hillside at the northern border of Aichfeld close to Sachendorf. The size of this regular rectangular terrain mark is about 18 to 24 meters. The depth of the ditches is about 50 to 75 centimetres. Based on the information of locals it could be identified as a one-time seedling nursery.

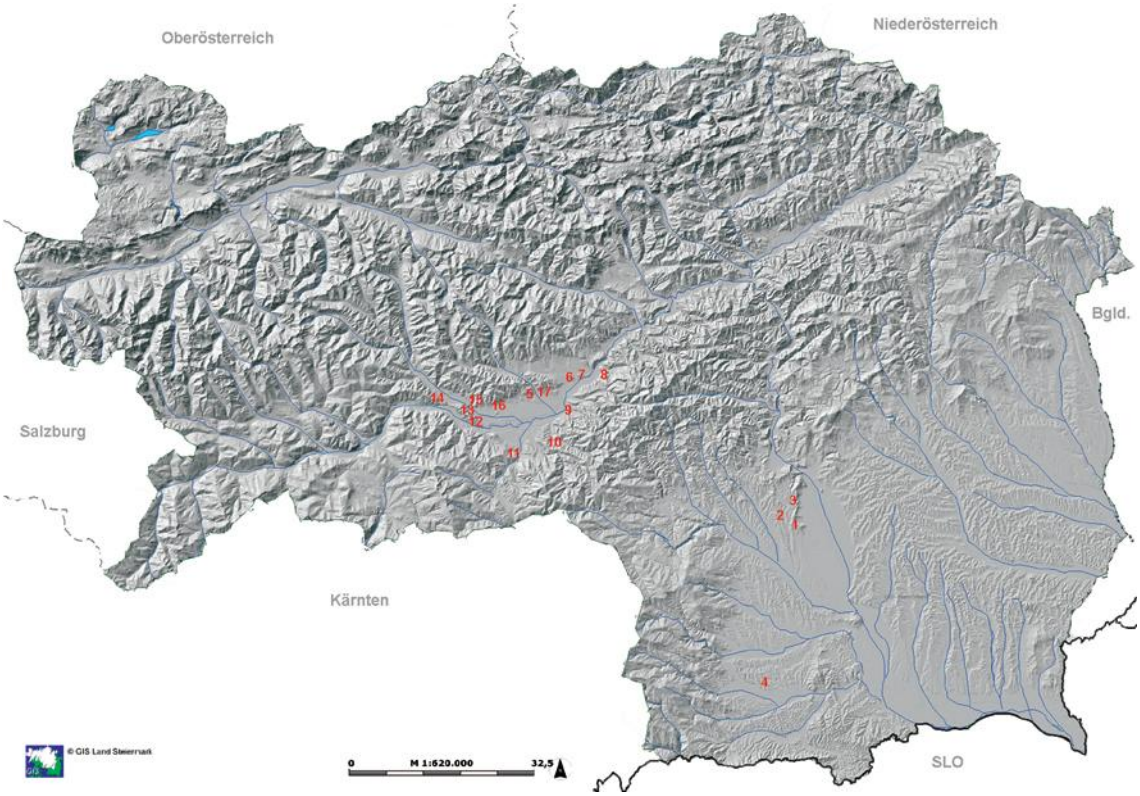

Fig. 4 – Map of Styria with the mentioned find spots: 1 Mitterriegel, 2 Mantscha, 3 Attendorf, 4 Taborkogel, 5 Flatschach, 6 Zuckenhut, 7 Sulzberg, 8 Schlosskogel, 9 Guggamoar, 10 Umadum, 11 Eppenstein, 12 Falkenberg I, 13 Falkenberg II, 14 Gerschkogel, 15 Hartleb, 16 Kirchbichl, 17 Sachendorf.

By the intensive analysis of the LIDAR-data of GIS Styria a substantial amount of new archaeological sites were detected until now although the work is still in progress. In addition many important facts about the position and the dimension of already known find spots could be gained. The connection between the single sites and settlements and the links between them have become visible. Also some characteristics of sites appear like the explicit visible terraces of hilltop-settlements in Upper Styria. Moreover in each case it would be helpful to continue analyzing aerial photos, old and new cadastres, old maps and the topographic facts parallel. In any case it is necessary to make surveys and check the terrestrial marks to differentiate the artificial modification and to find patterns for the further application of ALS-data. Furthermore the large scaled LIDAR-data analysis is a valuable instrument for the heritage of archaeological sites and helps to get a new view of the ancient landscape use.

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SESSIONS

Data Integration, Data Handling and Data Processing/Analysis

New advancing of the research on the architecture with concave and convex rhythms at Hadrian’s Villa: reconstruction hypothesis on the southern nymphaeum of the Piazza d’Oro

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Abstract: Thanks to the gratifying result achieved in the past years (ADEMBRI et al. 2011), we decided to further develop our investigation line on concave and convex friezes of the Piazza d’Oro in a more challenging way: the development of a wide virtual reconstruction of the southern part of this well known pavilion of the Hadrian’s Villa. The wider scope of this research needed the revision of the methodology used until now by splitting the general objective in smaller problems that could be solved with a certain degree of independence one in respect of the others. By a side we propose a progressive improvement of the data treatment carried out in the past years with the aim to achieve better and more manageable 3D models of the friezes, by the other side we present the increased database of figured frizes and other architectural decorations belonging to the southern nymphaeum of the Piazza d’Oro. We do decided to focus our attention on this issue for various reasons: the presence of former studies on the same theme, developed by means of traditional surveying technologies, that nowadays seem to be outdated for a lack of accuracy of the measures (HANSEN 1960; RAKOB 1967; CONTI 1970) and the presence inside the Villa of a variety of fragments (not only friezes) related to this nymphaeum. Moreover we present the development of a methodology based on the integration of two different surveys: one obtained by means of architectural laser scanner equipment and a more detailed one aimed at architectural decoration (column’s basis and shaft, friezes, mouldings, etc.) also integrated by Image Based Modelling Techniques. Due to the complexity of the project a new partner has been involved in the general research on Piazza d’Oro (Prof. Francisco Juan Vidal and the architect Isabel Martinez-Espejo Zaragoza Ph.D. student of the Universidad Politécnica de Valencia) as explained before the main outcome (the complete virtual reconstruction), will be the product of a sum of integrated research.

Introduction

During the last two years we advanced in the research on Villa Adriana mixtilinear architecture fronting the theme of Piazza d’Oro’s southern pavilion, formed by a series of rooms characterized by an entablature decoration with two main figurative themes: *hunting Erotes* and *Sea-Thiasos*[2]. The study intrinsic complexity, due to Hadrian’s unusual architectural features and at the same time to the intense divestment suffered by

[2] This last theme is also present in the Maritime Theatre on one side of the entablature (ADEMBRI et al. 2010: 448); by the other side there are cherubs riding chariots towed by different real or imaginary animals in a circus race.

the Villa, needed to split the research in different work packages, carried out by two linked teams, with the aim to manage all the collected data with proper care and to share different ideas for a reliable virtual reconstruction. Data processing and archaeological/architectural investigation were shared out using simple criteria that is to keep all the parts of the southern pavilion under common interpretation tools, going on step by step. So, it was decided to draw an accurate map of the area and a 3D model, with the aim to provide a general reference for each following step. Starting from these drawings and digital models as a base for all the consequent considerations, one research team decided to concern with the hunting friezes of the two lateral porches and our team to go on in focusing the attention on the southern curvilinear *nymphaeum*, characterized by a very rich architectural decoration[3].

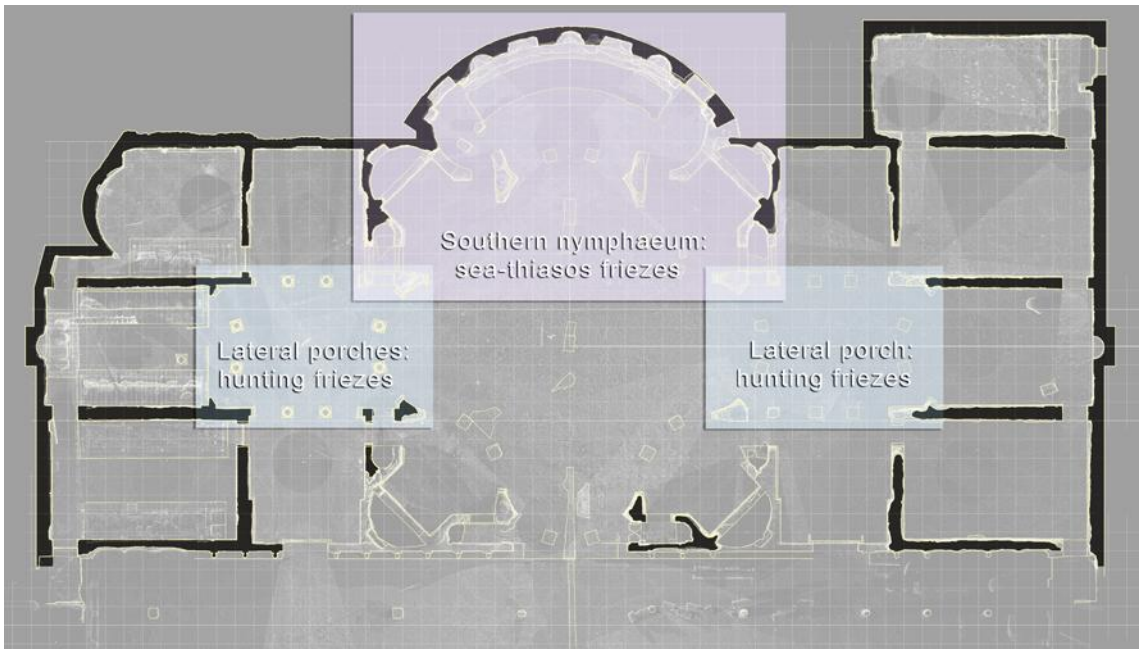


Fig. 1 – Plan of the Piazza D'Oro's Southern part. In evidence the two porticos and the nymphaeum (Copyright: Adembri, Di Tondo, Fantini, Martinez).

During the past years we developed a database of the decorated pieces of the entablature (ADEMBRI et al. 2011), pointing out for every scanned frieze a data sheet with all the formal features of the specific element of the entablature or of the cornice: ID of the element, location inside the Villa or other museums, subject, features of the architrave (kyma, pearls and astragals, lesbian kyma, etc.), if it presents decorated friezes on both sides and which was the theme on a side and on the other, curvature and bend radius. By means of a synoptic frame it was possible to establish a probable location of every fragment belonging to our database.

[3] The team consists of researchers from different universities and institutions: Soprintendenza per I beni archeologici del Lazio, dott. Benedetta Adembri; Università degli Studi di Firenze, dr. Sergio Di Tondo, Universidad Politecnica de Valencia, Instituto de Restauración del Patrimonio, dott. Filippo Fantini, Universidad Politecnica de Valencia, prof. Francisco Juan Vidal, prof. Pablo Rodriguez Navarro, prof. Maria Teresa Piqueras, PhD. Student Isabel Mtnez-Espejo Zaragoza. Laser Scanner survey in collaboration with Leica Geosystems Italia, arch Federico Uccelli, dott. Michele Curuni, arch. Valentina Albano. A special thanks to prof Pier Federico Caliari and to the students of the Accademia Adrianea di Architettura e Archeologia.

The comparison between the angle present on the molding of the frieze called POS 02 (Fig. 2)[4] and the masonry of the nymphaeum had already validated the hypothesis that the frieze belonged to nymphaeum’s entablature (ADEMBRI et al. 2010). The next purpose was to verify the original frieze’s position in the nymphaeum’s entablature and the entire architectural order.

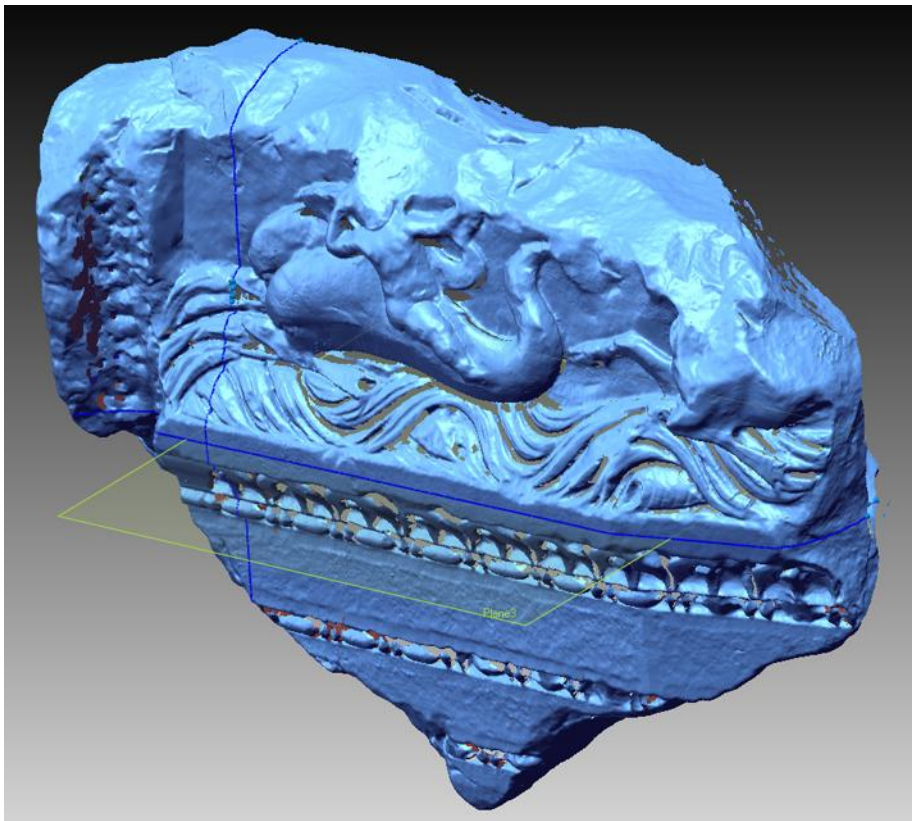


Fig. 2 – Frieze POS 02: thanks to reverse modelling tools it was possible to align and section the moulding for obtaining formal features relevant in the virtual reconstruction pipeline.

Purpose

Starting from the results obtained last year, the purpose was to formulate a reconstruction hypothesis for the entire architectural decoration that characterized the nymphaeum. The survey campaign, carried out in September 2011, was planned according to this purpose; the research team leaded a survey of the fragments of architectural decoration belonging to the nymphaeum and now preserved in Hadrian’s Villa (column base stored in Canopo Museum and the fragments of grooved column in “giallo antico” marble preserved in Cento Camerelle repository) and the ruins of internal and external masonry of the nymphaeum.

[4] The friezes labels match to the database published in ADEMBRI et al. 2010.

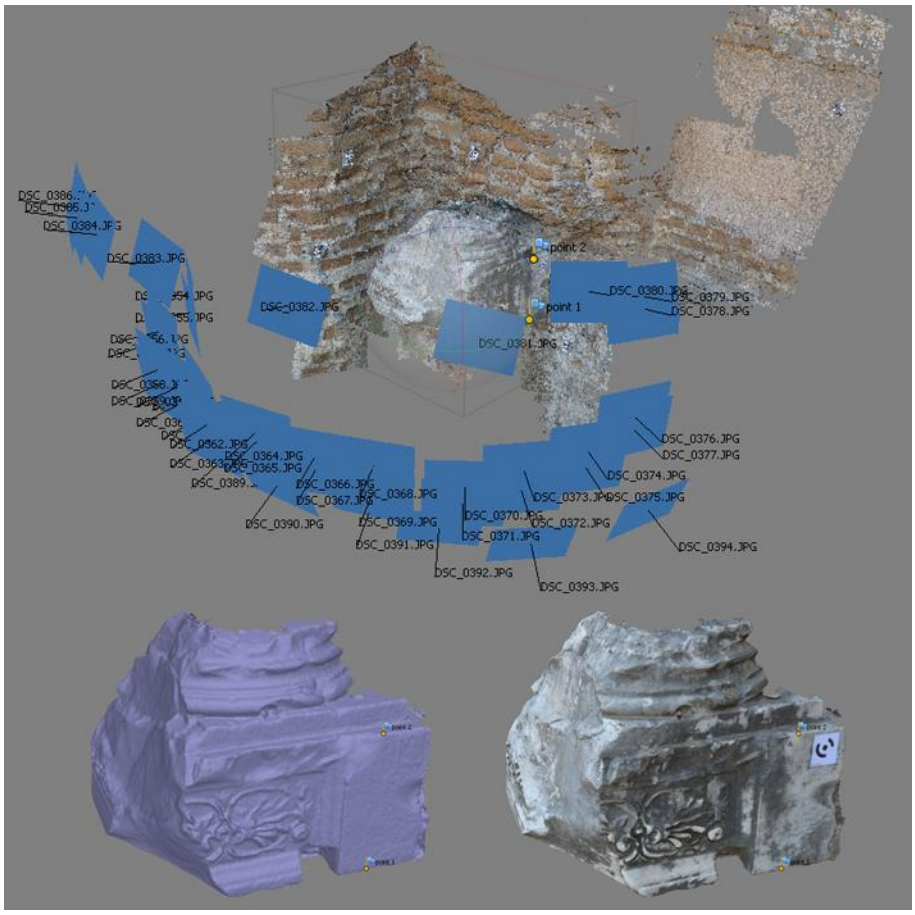


Fig. 3 – For a fast survey of the architectural decoration still present in the nymphaeum, so as other friezes it was used photogrammetric techniques (Copyright: Fantini, Rodriguez-Navarro).

Methodology approach

The instrumental metric survey has allowed us to acquire an amount of data suitable to metrological[5] interpretation about architectural evidence and fragments of decoration. The entire Piazza d'Oro southern hall, in the inner portion of the monument and in the outer side facing the hills of Santo Stefano, were surveyed by means of terrestrial laser scanner, supported by a topographical network. Data acquired have made it possible to valuate accurately the nymphaeum masonry thickness and the heights of inner and outer levels of the soil. Architectural decorations were surveyed by means of different survey techniques. The base of the column stored in the Canopo Museum was surveyed thought laser stripe scanner; while the eastern base of column and plinth (still in good conditions), so as the fragments of grooved column preserved in the

[5] For *metrology* we intend a methodology used for investigation and validation of hypothesis on the design process that led to the construction of a building. The meaning of this word *metrology* is due to the assumption that ancient measuring units for lengths, areas, volumes can let us understand a relevant part of work done by ancient architects. Through the conversion of a survey measuring system to the anthropometric one used during roman imperial age it is possible to guess the various phases of the design process. Of course the process is more extended than a simple confrontation with measures, because this methodology also uses cultural criteria taken from treatises: for example Vitruvius's rules about architectural design so as other ancient texts that in the whole concur to let us understand the phases of the ancient designs. In our opinion it should be called reverse design because the word metrology overlaps with other scientific fields.

repository were surveyed by means photogrammetric techniques (structure from motion). The development of an optimized and customized pipeline for data processing, have allowed us to manage heterogeneous information inside a single workspace where interactively validate or confute the considerations based on metrological preliminary phase.

Notes on former studies: methodology development

In general the development of our research has always been the product of three different steps: laser scanner survey for obtaining 3D accurate models of archaeological remains and decoration, then an extensive use of reverse modelling techniques for determine formal features and relevant measures (bend radius, angles) that could provide clues for virtual reassembling and the third part has to do with an optimization process of dense meshes in order to provide “easy to use” textured models. This last step takes a lot of the time in the whole process, but is very important because permits the use of high detail models inside a single 3D environment where is possible to review the suggested alignment of the fallen pieces.

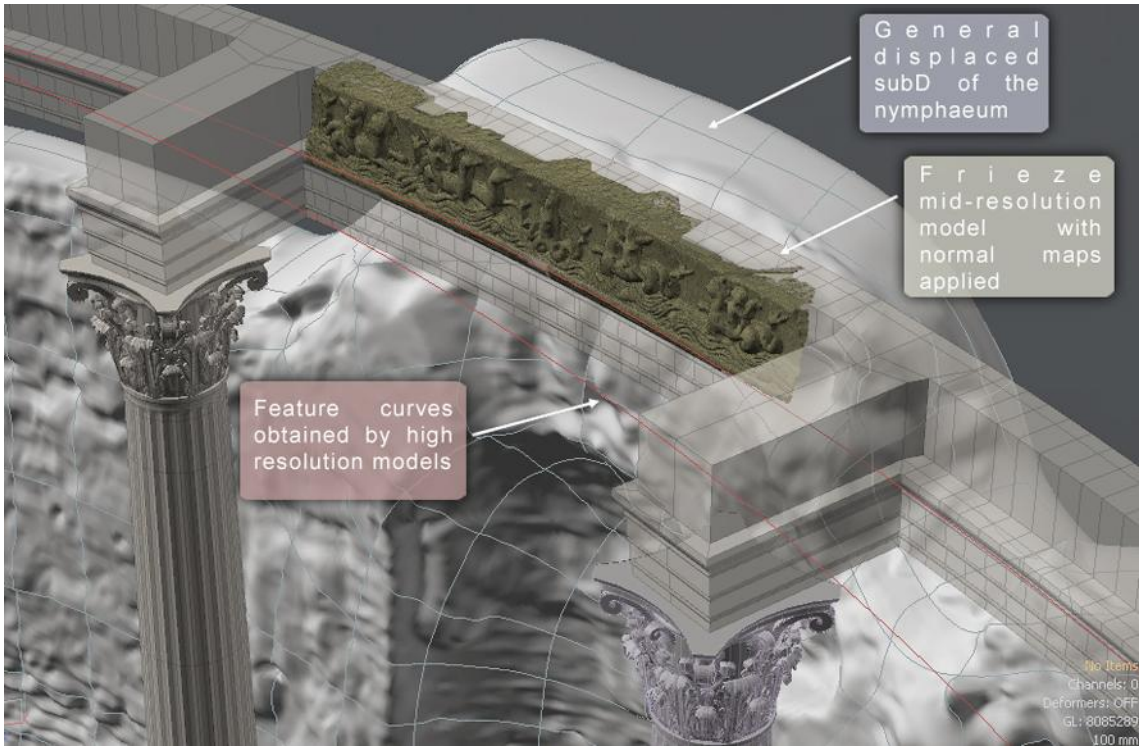


Fig. 4 – The set of models that contribute to the virtual reconstruction: feature curves, variable level of detail model (displaced subD) and meshes.

The procedure for achieving the best fitting of a frieze, or marble decorations, with the corresponding supposed masonry walls shall not get rid of an interactive validation (fig. 4): the first template is obviously a 2D approximation, but only in 3D is possible to recognize a possible misunderstanding or find the better alignment where constructive lack of accuracy produced distortions and deviations from the a theoretical geometric model and the real word. In general this kind of interactive approach to virtual anastilosis is made quite difficult because of the computational weight of the scanned remains: the most popular solution is to

construct high detail models that once decimated can be more easily imported in a 3D application. Obviously the geometrical reduction cannot be restored (it is an irreversible process) and in some cases the decimation risks to “wash away” important geometric features that could confirm or contradict assumptions that in general are based on 2D reference drawings. These references can be extracted directly from the point cloud or from high resolution meshes and constitute the base for an overall interpretation process from the whole building to its details. This is a kind of “reverse design” where ancient measures can give us a confirmation of the reliability of a hypothesis. In the case of the central part of Piazza d’Oro southern aula we decided to improve both the quality of the representation and the accuracy of the models. During former experiences (Maritime Theatre) we used optimized low resolution models with normal maps applied; this technique comes from video games interactive applications and it is not aimed at the accurate representation of high detailed models because it is aimed only to a better model’s visualization. In fact when a model is strongly decimated (ADEMBRI et al. 2010: 139) shading problems can occur and in general a lack of reliability of the representation convert it in an accessory illustration more than a scientific tool for the understanding of an architectural ancient aspect. In this last advance of the research we refined our customization of different applications from the field of reverse modelling and computer graphics for entertainment. Mainly *subdivision surface* (subD) and *displaced subdivision surface* (displaced subD) helped us in a complex reconstruction process.

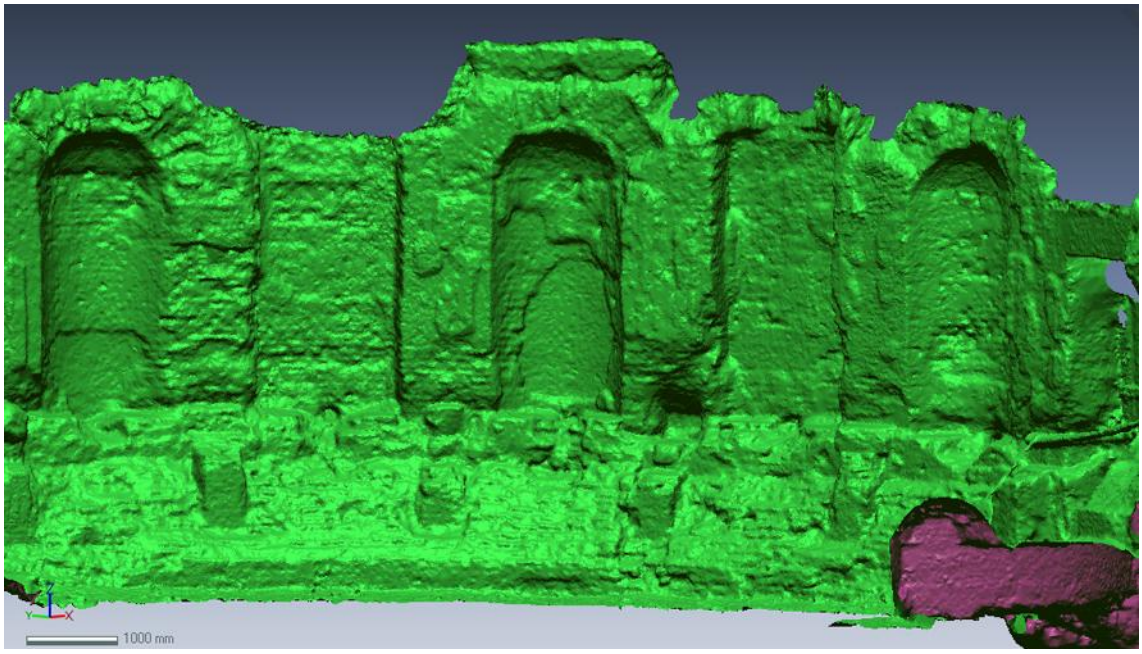


Fig. 5 – Partial model of the nymphaeum. This high resolution mesh is made of 1222389 polygons. Such high-poly models are quite difficult to manage inside a complete reconstruction: the usual solution is to lower the mesh resolution with the consequent lack of reliability of the model.

Testing of new tools for the research

Displaced subD models are often used in the field of computer graphics, when it is necessary to animate virtual character obtained by digital sculpting or made with clay by an artist and then scanned. Such models,

once the modelling phase is completed, are not so easy to manage because they are formed by millions of polygons and in practice cannot be animated using virtual skeletons, morphing, etc. Our experimentation with displaced subD in the field of virtual reconstruction started with some questions: would it be possible and convenient to use such representation technique to improve visualization? How long does it take to convert a mesh model in displaced subD? Renders and animations can really take advantage of this technique? During the past decade entertainment software house developed different solutions to let visual effects artists use “heavy model” made up by millions faces inside their animation systems (fig. 5).
The solution they found was to reconstruct the full resolution model with a simple mesh essentially made of four side polygons (quad dominant, fig. 6) and then converted it in a variable detail model with a greyscale map applied as displacement (fig. 7).

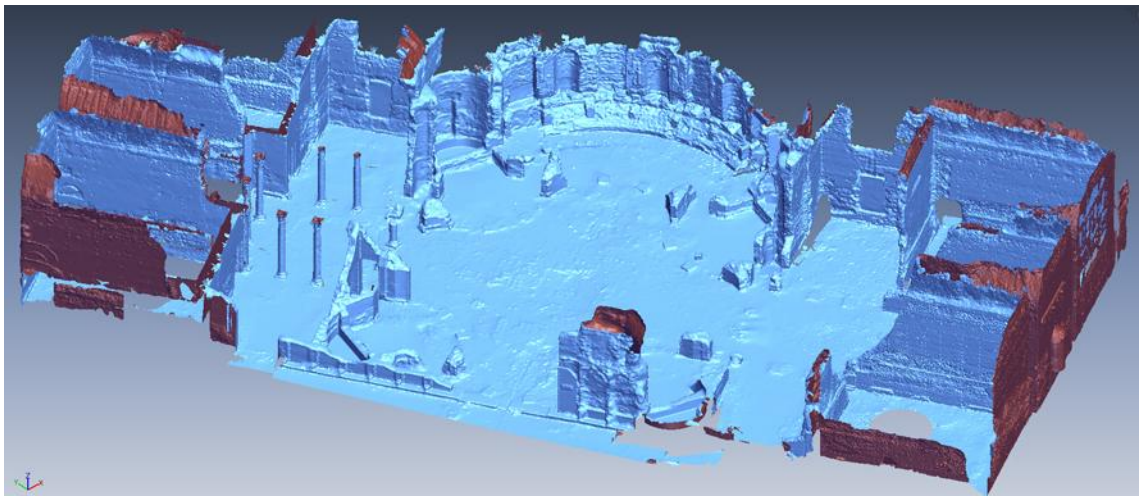


Fig. 6 – Image of a complete low-resolution model of the southern part of Piazza d’Oro (Copyright Fantini, Mtnez-Espejo Zaragoza).

The importance of this reconstruction process is attested by the presence of new modelling tools dedicated to the so called “retopology”: a set of tools that allow the users to cover a high-poly mesh with a coarse new topology made of quadrilateral polygons. Between the benefits of this kind of models there is the variable level of detail or LOD (level of detail) that in general is considered a prerogative of NURBS modelling application. In general NURBS models are produced by means of two different approaches: reverse modelling and direct modelling. The first methodology is implemented inside software like INUS Rapidform, Raindrop Geomagic and Innovmetric Polyworks that have been developed for other fields such as industrial design and reverse engineering. In general this approach convert high resolution meshes into mathematical models formed by a clean and continuous set of surfaces called “patches” by means of automatic or semi-automatic procedures based on various steps (detection of regions, feature curves, etc.). The other approach consists in sectioning the point cloud or the high resolution mesh along specific planes (offset of the ground plane, symmetry planes, radial array of planes centred on a specific axis, etc.) for extracting polylines or spline curves that once exported to modelling software can be used as references for the construction of a simplified 3D model. In our opinion these two approaches doesn’t fit with the kind of study we are developing for two reasons. Both reverse modelling and direct modelling (from a collection of sections) provide simplified version of the original survey, more a geometric idealization than a real

documentation: NURBS modelling tools are designed for the development of new projects more than documenting the irregularities caused by degradation, decay, cracks and deformation, etc. Moreover there is the texturing problem on NURBS models. UV mapping tools inside software solutions from the entertainment field provide accurate and performing methodologies, more flexible if compared with those implemented inside mathematical modelling applications. The main aspect of displaced subD is the capability to increase the geometric resolution during the computation of the rendered image (FANTINI 2010: 152); obviously it could not be possible in the case of an optimized mesh model with normal maps applied. Another essential aspects of displaced subD is that the displacement map used for re-establish the detail of the high resolution model from scanner is obtained through a standard procedure and is not the result of an empiric photo editing.

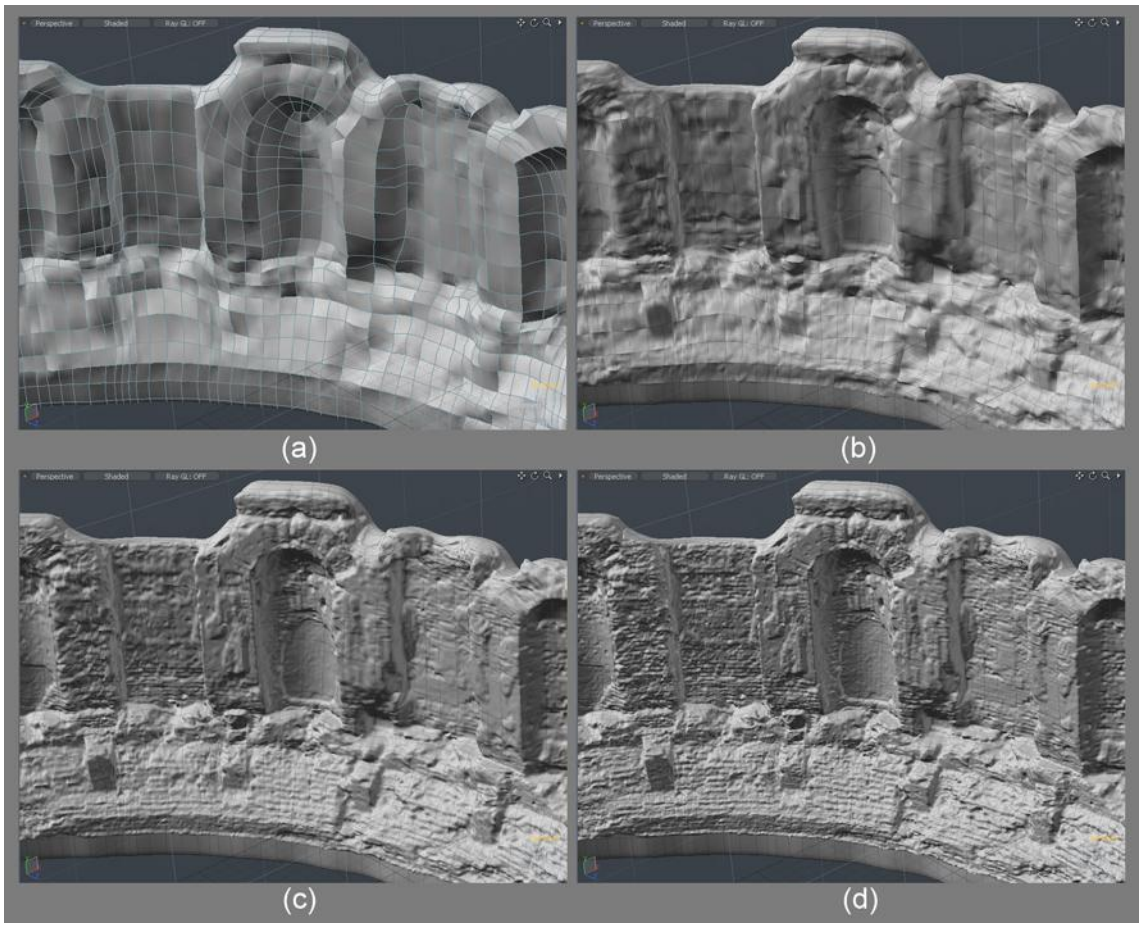


Fig. 7 – Once converted in a displaced subD the model can be increased or decreased of detail interactively. The more convenient thing is that the geometrical detail is not stored in a specific mesh, but in a displacement map obtained through a render-to-texture procedure.

Improvement and customization of reverse modelling tools

The methodology adopted in this research on Piazza d'Oro is built on the experience done with the former investigation on the Maritime Theatre. As we mentioned before the accuracy problem of the representation has always been one of our aim but is just a part of the whole process which is also based on a consistent use of reverse modelling techniques.

First of all there is the correct positioning of all the cutting planes aimed at obtaining the sections, both of the friezes and of the masonry walls, which can be useful for repositioning the fragments. The density of information provided by these high resolution models gives back the better templates for drawing the supposed circles of the mixtilinear entablature.
However, another problem that should be commented is about the construction accuracy inside Villa Adriana. In many cases it is possible to detect small rotations of supposed parallel walls or deformations of curved semi-circular shapes (HIDALGO 2010: 116). Those errors can be ascribed to two main causes: high speed of construction and also technical-formal experimentation.
This preamble it is necessary to understand how to treat data exported from reverse modelling application such as splines (IGES file format) , or polylines (DXF file format) because these templates have to be ponder by means of some practical and theoretical “filters”: sometimes metrology or reverse design can help in properly considering the suggestions coming from a survey, in other occasions it should be remembered the role of deteriorations and restorations in changing shape and measures of the ancient building.
By this point of view it is important to make the effort to choose proper cutting planes for the identification of significant data; those planes in general correspond to the triad of the *dispositio* from Vitruvius: Icnografia, orthografia and scaenografia. In the first of the ten books of the *De Architectura* the Latin author explains the *dispositio* which contains three different steps forming the design process in the classic age (BARTOLI 1997): the map or the traces made on the soil (ichnografia), the erection/extrusion of those traces, as a facade (orthografia), and the involvement of perspective/subjective perception in the design of a building (scaenografia).

Metrological considerations and proposal for the reconstruction

The nymphaeum was the end of a complex architectural design characterized by a mixtilinear central space conceivably covered by some kind of concave-convex vault, similar to the one partially preserved in the octagonal room of the Small Thermal Bath in Hadrian’s Villa. The role played by this exedra is similar to the long and narrow corridor at the southern part of the so called Serapeum of the Villa and the relation appears even clearer if we focus our attention on the global composition and some other aspects: a central vaulted room with three everted spaces in the quadrants. In this case two are the porticos with haunting friezes, another is the terminal nymphaeum characterized by large niches pouring water and a fourth could be a connection element with the porch. Both the nymphaeum and the narrow terminal corridor of the Serapeum are placed to the southern terminal parts of huge buildings characterized by the presence of water and fountains where also sunlight provided a scenographic effect because it entered from behind the walls bearing the vault.
The nymphaeum at the south of the Piazza d’Oro’s central hall has been analyzed comparing its relevant measures (expressed in the SI) with the ancient measuring systems based on the length of roman foot which is considered equal to cm 29.56 as well as attested by other buildings made in Rome during the Hadrian’s age, for instance the Pantheon (CINQUE 2010: 19–53).

The bend radius R4 (fig. 8) identified in the frieze with the sea monster (POS 02) is greater than the one detected at the foot of the nymphaeum's wall (R4> R3), because it is thinner above the niches to receive the marble entablature to whom the frieze belonged to.

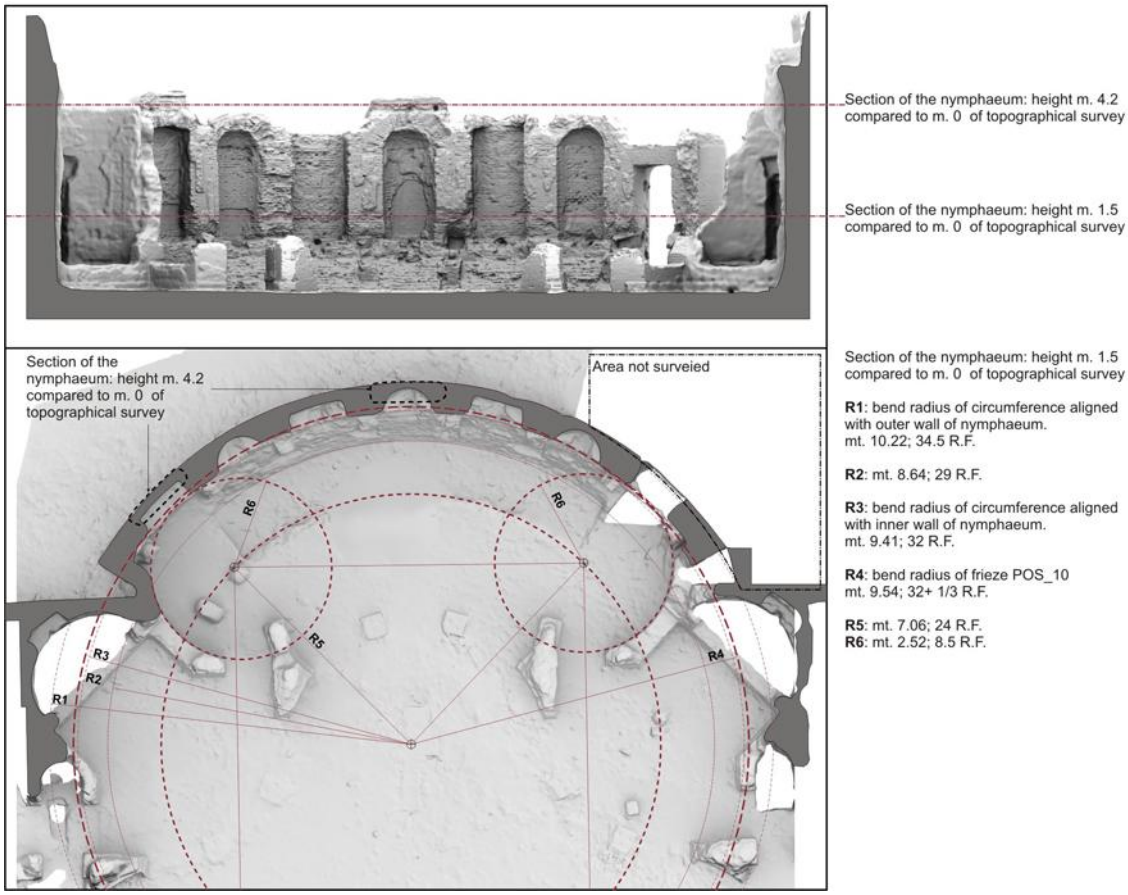


Fig. 8 – Metrological investigations on 3D model.

This shape of the masonry, although stressed by the flawing of time and the obliteration of the marble elements (entablature and capitals), shows the original form of the inner structure that was probably designed with a recessed to insert the marble block of the architrave and the frieze[6].

In fig. 9 we can see the reconstruction of the architectural order starting from the data acquired during the survey campaign; the results were compared with the treatise on architectural design by Vitruvius and with the hypothesis formulated by HANSEN (1960). In this case the identified module (equal to 1+1.5 roman foot) seems to arrange the design of the whole facade according to Corinthian architectural proportion (Roman Corinthian composed by column above plinth).

[6] The study of the architectural order compared with the height of the current wall seems to suggest, as well as in the Maritime Theatre, that the cornice composed by large marble blocks, was located either above the entablature and the masonry covering the entire width of the wall.

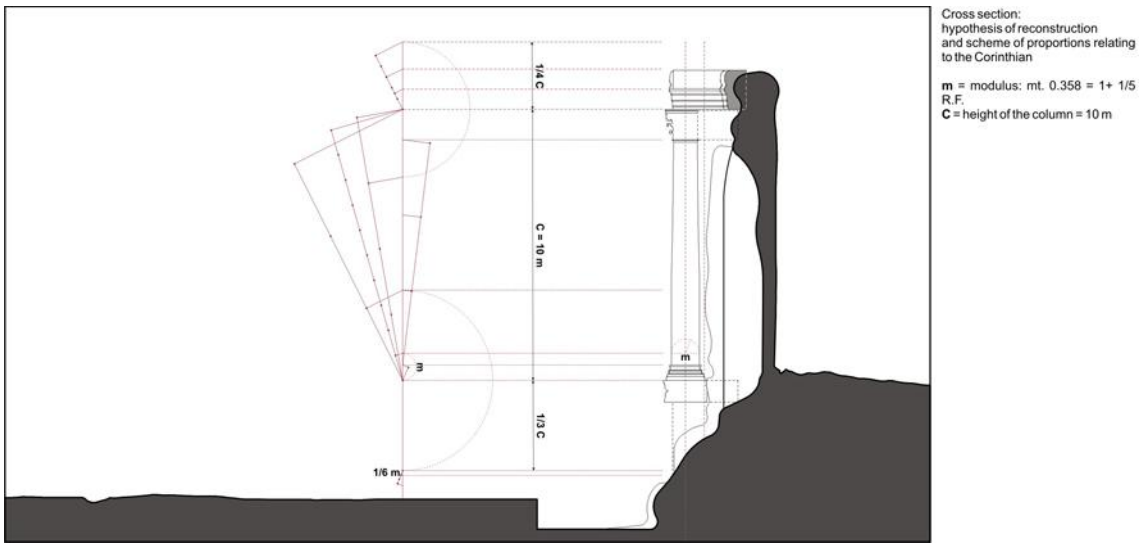


Fig. 9 – Reconstruction of the architectural order starting from the data acquired during the survey campaign.

Note that the typical tripartite design characterizing the nymphaeum’s facade is also suggested in the arrangement schemes of the emperor’s rooms, decorated with marble crustae as well as it is confirmed by the position of the holes used to hook the marble slab to the masonry at the so called “Edificio con Tre Esedre” (ADEMBRI and CINQUE 2006).

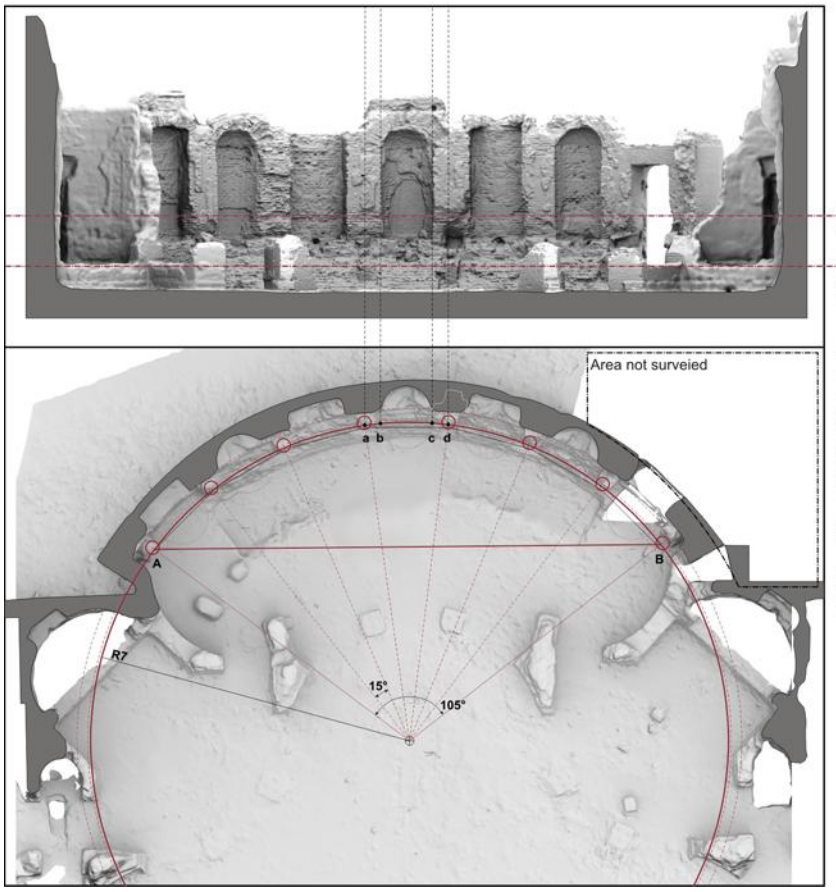
The cross section of the nymphaeum (fig. 9) shows the current different height of landing levels between the inner and outer part; this scheme reproduces the original land placement, supporting the hypothesis that the inner side of the nymphaeum was built by digging part of the tuff bed on which is laid down the building. Indeed the foot of the wall, outside, matches with the actual level of soil and with the level of the ancient water supply system (fistulae) as well as it is shown by the holes in the niches not yet restored.

The figures 10–11 show the compositional scheme of the nymphaeum’s inner concave wall on which is based the arrangement of architectural decoration (cfr. Fig. 12). We considered the arc belonged to the circumference tangent to the plinths of the columns between points A and B and matching to the position of the first and last plinth of the concave wall. The length of this arc, which is equal to 56 Roman feet, can be divided into 7 parts, each one 8 feet long.

Each part inside is further divided into three parts; in the central one (5 feet long) is located the niche and in the two lateral strips (each one 1.5 feet long) is placed the plinth of column.

The usage of full-value measures, easily divisible and manageable during the construction phase, was a habit of roman builders that simplified the transmission of information between the architect and the workers. In addition, the fact that the full-value measure is established on the arc of circumference, may also suggest useful information about design process. The composition of nymphaeum’s facade, which is easily designed according to a linear development, is wrapped along an equal length arc of circumference[7].

[7] The verification of this procedure, which is already tested successfully on the circular porch of the Maritime Theatre is still in progress.



Section of the nymphaeum: height m. 1.5 compared to m. 0 of topographical survey

circumference aligned to the eight bases of columns that arrange the nymphaeum facade.

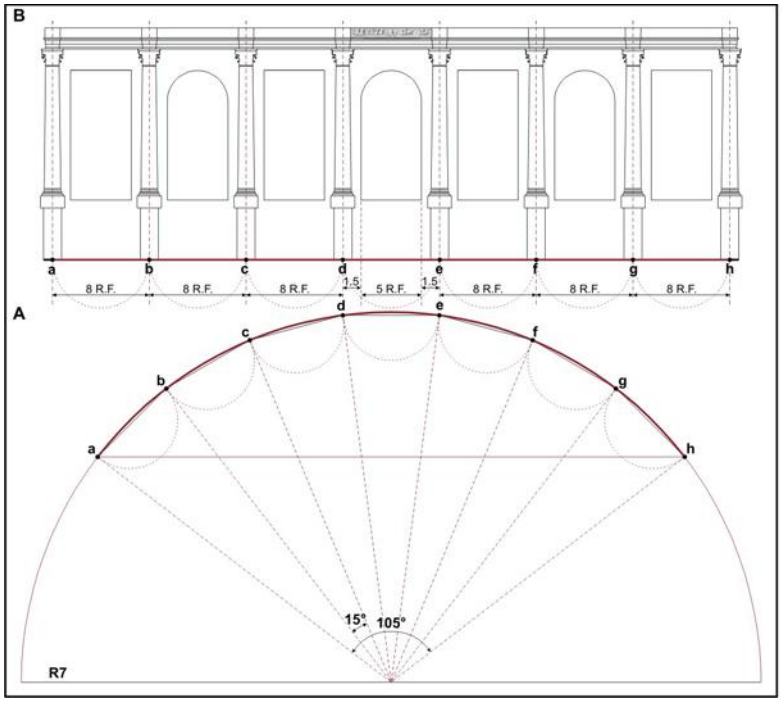
Section of the nymphaeum: height m. 1.5 compared to m. 0 of topographical survey

R7: radius of circumcircle of polygon with 24 sides. The circumference is aligned to the eight bases of columns that arrange the nymphaeum facade.
mt. 9.03
30.5 R.F.

AB: lenght of circumcicle from A to B = m. 16.55 = 56 R.F.

ab: lenght of circumcicle from 1.5 R.F.
bc: lenght of circumcicle from 5 R.F.
cd: lenght of circumcicle from 1.5 R.F.

Fig. 10 – Metrological investigations on 3D model.



A: scheme of the circumference aligned to the eigh bases of columns that arrange the nymphaeum facade.
R7: radius of circumcircle of polygon with 24 sides.
mt. 9.03
30.5 R.F.
ah: lenght of circumcicle from a to h = m. 16.55 = 56 R.F.
lenght of sections of circumference **ab** = **bc** = **cd** = **de** = **ef** = **fg** = **gh** = mt. 2.364 = 8 R.F.

B: unwrapped representation of curvilinear shape nymphaeum facade.

Fig. 11 – Metrological investigations on 3D model.

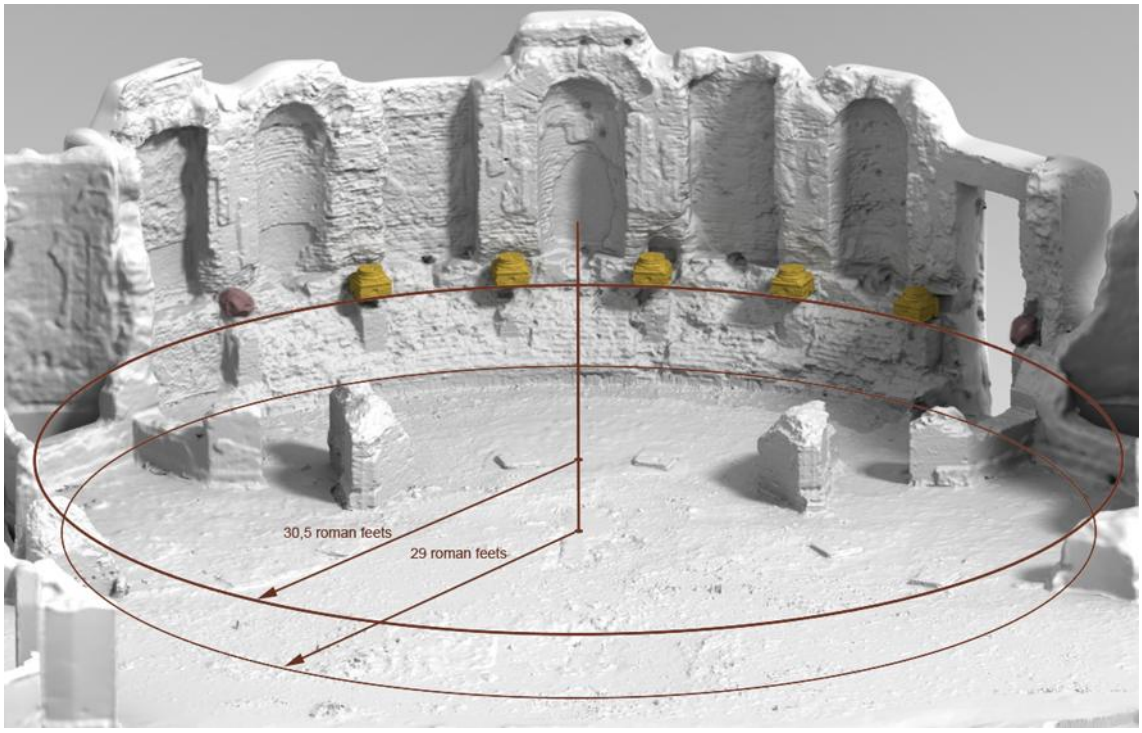


Fig. 12 – Metrological investigations on 3D model.

Fig. 13 – Virtual reconstruction of the nymphaeum’s order.

The reconstruction hypothesis of the whole nymphaeum's facade (figs. 13–14) allowed also to determinate length of each parts of the entablature, which were applied to the back wall (just above the niches) between the two columns. This length is equal to the one of the frieze with maritime monster (POS 10) that it's possible to consider complete. According to the final comments and using three dimensional models, directly acquired during the survey campaign, it was possible to propose a reconstruction solution of the southern nymphaeum's architectural decoration[8].

Fig. 14 – Virtual reconstruction of the nymphaeum's façade. On the left side the positioning of the frieze POS 02, which belonged to the main hall of the southern pavilion.

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[8] The POS 02 frieze's positioning showed in fig. 14 has been already published in ADEMBRI et al. 2011.

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Hunting friezes of the Piazza d'Oro at Hadrian's Villa

New hypothesis for a virtual reconstruction inside an integrated research strategy

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Abstract: This project is presented as a line of research that analyzes an anastylosis of some figurative friezes of hunting themes held at La Piazza d'Oro Villa Adriana (Tivoli, Rome, Italy) in the 70's. However, this anastylosis was done with an arbitrary position in some cases. Shortly after it was decided that it is wrong and it is disassembled. With this background, it creates a line of research using new technologies. This line of research, as a result of a collaboration between the "*Soprintendenza Archeologica per il Lazio*" and "*Instituto Universitario de Restauración del Patrimonio" de la Universidad Politécnica de Valencia*, is intended to integrate with other research on the building. It is proposed to use new technologies to conduct a review of the anastylosis already done in the 70s by using the 3D surveys and some models with high level of detail, and by designing a more accurate anastylosis.

It is intended to apply the same methodology to the friezes of hunting that is already being used in the same Piazza d'Oro and the Teatro Marittimo. In this case, however, not only two types of different scanning laser surveys (architectural and detailed) are going to be used, but also solutions to share the partial results in a common database for several universities are going to be developed. Besides the typical methodological contribution of archaeological field research (Research Archivist, confrontational style of the pieces ...), in this case, it will add a series of typical morphological metrics and linkages of research in the architectural field.

We try to clarify some issues are still open about the nature and construction of the two halls with hunting friezes. Getting optimized models of the friezes that can be used in a common research perspective. Adding the friezes of hunting to the database of digital models of the Piazza d'Oro.

Keywords: Laser Scanner Survey, Data intregration, Virtual anastylosis, Imperial Roman Architecture, Hadrian's Villa.

Introduction

This research, which is still in its initial stages, intends to obtain a hypothesis as to the complex nature of the "Piazza d'Oro"'s architecture. The reliability of the result shall be guaranteed through the use of scientific methodology, based on full and detailed studies and borne out by advanced and innocuous technology for the ruins: the precise and meticulous uplifting of the remains using 3D laser technology; the metric and geometric study of the plans; the virtual anastylosis of the preserved archaeological pieces; the figurative, composite and architectonic coherence and its correlation with historical testimonies; the examination of the

static viability of successive models of approximation … Studies that will concur on a final hypothesis that will, among other things, allow former anastylosis, such as the one formulated during the sixties, to be reviewed.

Hadrian’s Villa and the “Piazza d’Oro”

The “Piazza d’Oro” is part of the architectonic complex of Hadrian’s Villa which served as a retreat for the Roman Emperor Hadrian. The aforementioned complex was built as a retreat from the palace on the Palatine Hill in the city of Rome since it displeased him due to his relationship with the Senate which was by no means cordial. It was here that he spent the latter years of his reign and governed his empire.
The villa was made up of four groups of buildings: the “Piazza d’Oro” next to the “Vestibule”; the “Nymphaeum”; the “Courtyard of the Libraries” and the “Palace Peristyle”. The “Ospitali” made up that which is commonly referred to as the “Imperial Palace”. A second group of buildings, with a different orientation, was made up of the “Rocca Bruna” and the “Academy” (also known as the “Small Palace” or the “Minor Palace”). It is in the first group (or Imperial Palace with its views of Tivoli) where the emperor used to stay during the winter months. However, once the summer arrived he preferred to inhabit the buildings of the Academy (with views of the Roman countryside and the sea) (AURIGEMMA 1996: 20).

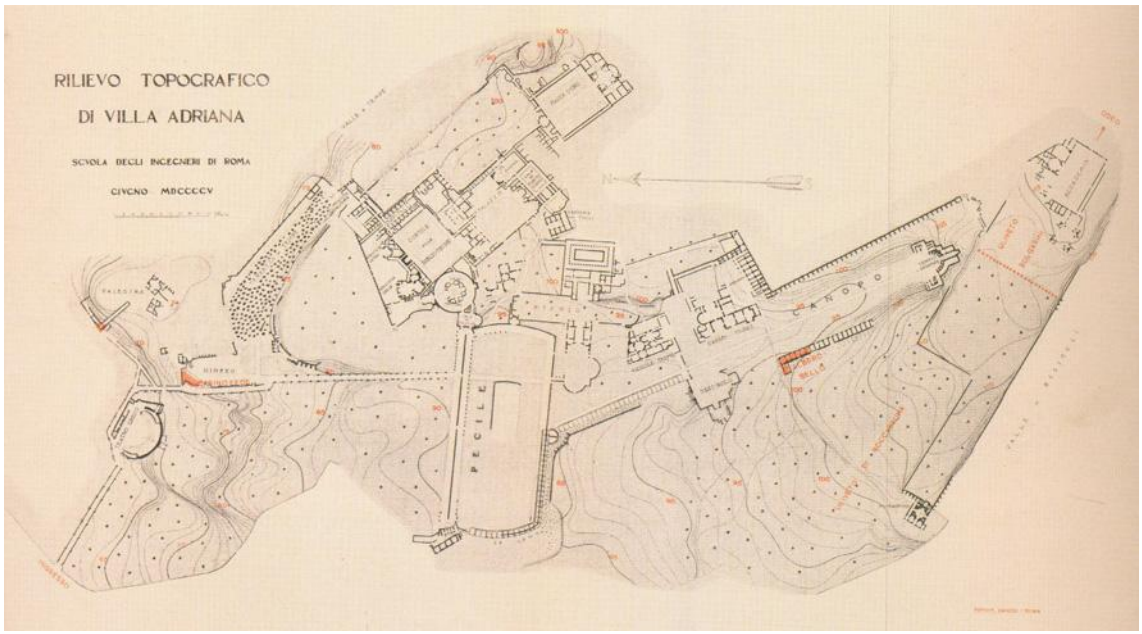

Fig. 1 – Topographical Uplifting of Hadrian’s Villa 1905 (SAPELLI RAGNI 2010: 172).

There was also a third group of monumental buildings made up of the “Pecile”, the “Library Chamber” (now known as the “Philosophers’ Chamber”), the “Stadium”, and the buildings next to the stadium, be they to the west (“the building with three exedra and fountain”), or be they to the east (the building with cryptoporticus and fishpond”). This last group was made up of the “Canopus” and the two complexes of the “Baths”: respectively the “Small Baths” and the “Large Baths”.
The Piazza d’Oro is situated to the east of the Villa and located on the Foso del Agua Herrada Valley or “Valle de Tempe”. The Piazza can be considered to be a large porticoed garden or peristyle. It is made up of

mixtilinear complexes which are presumed to be the main features of the place: a vestibule with one of the first gallonada vaults in the history of architecture; the pavilion at the back set up around an environment with an unprecedented cruciform silhouette defined by an uninterrupted winding concave-convex line (about which it is not known with any degree of certainty as to how this was covered) and a side pavilion displaying an equally unprecedented sinusoidal façade in mirror on a semicircular basin towards a wooded valley (BOZZONI et al. 2010: 329).

The “Piazza d’Oro” Hunting Friezes (SIRANO 2000)

The Piazza d’Oro contained rich decoration in accordance with the elegance of those different types of architecture of which it was made up. Some of these can still be observed such as the few in situ mosaics or the remains of *opus sectile* in the rarest and most appreciated marble. Besides the sculptures unearthed during previous excavations, nor can the topiary art which is prominent in E. Salza Prina Ricotti’s research be underestimated.

Fig. 2 – Anastylosis carried out during the 60s.

From among this decoration one must bear witness to the friezes appearing on Greek marble with “Amorini” hunters in maritime processions decorating the main environments of the southern buildings. The surviving fragments can be found distributed among Vatican Museums and Hadrian’s Villa, discovered during renaissance excavations.

Years later, during the 1960s, the material was removed in order to carry out an anastylosis, in most cases with fragments being placed arbitrarily and dangerously on architraves of reinforced concrete.

According to F. Rakob six groups stand out as regards likely positioning. According to him the hunting scenes decorated the spaces adjacent to the Court and those of the maritime procession decorated the apses of the fountains in their angles and the nymphaeum positioned on the axes of the complex.

Nowadays 27.03 metres of frieze decorated with hunting scenes and 10.4 metres of frieze decorated with maritime can be measured with the linear development of superficial elements and are included in the Vatican Museums and the Pecile. Bearing in mind that in some cases the friezes appeared on both sides, it is considered that the hunting scenes would cover 23.67 metres at the very most, as opposed to the estimated total of 40 metres of entablature.

In ancient art the subject of hunting expressed heroic and aristocratic ideals. Already during Republican Rome, hunting became a symbol of the Hellenising noblesse as an instrument of gaining political consensus via spectacles. Furthermore, according to sources, the Emperor is described as a passionate hunter, a subject which is undoubtedly reflected in the friezes. In the friezes of the Piazza it can be seen that they aim to clearly show hunting within a natural context by placing trees in the background of a wild and typically Mediterranean environment. Furthermore, the “*Amorini*”’s mode of combat (nude, on foot, with no other weapon to be launched such as stick or arch) glorifies the heroic and warlike aspect of hunting as is previously mentioned.

Fig. 3 – Scanning with 3D laser technology of a frieze with hunting subject (April 2011).

Methodology

As a starting point we consider studies about the Piazza d'Oro by different authors such as Francesco Sirano "*Adriano, architettura e progetto*", Charles-Louis Girault "*Italia Antiqua*" (GIRAULT 2002), Graziella Conti "*Decorazione Architecttonica della "Piazza d'oro" a Villa Adriana*" (CONTI 1970), Erik Hansen "*La "Piazza d'oro" e la sua cupola*" (HANSEN 1960) and Andrea Moneti "*Nuovi sostegni all'ipotesi di una grande sala cupolata alla "Piazza d'Oro" di Villa Adriana*" (MONETI 1992).

The studies carried out up to the present time have allowed us to clarify neither the subject of the hunting friezes nor its relation with the marine thiasus-style friezes of the Piazza d'Oro in a conclusive manner. The use of new types of technology shall help to clarify this situation, which shall contribute towards resolving the aforementioned mystery. To this end a new uplifting with advanced technology has been carried out via the interaction of different uplifting techniques.

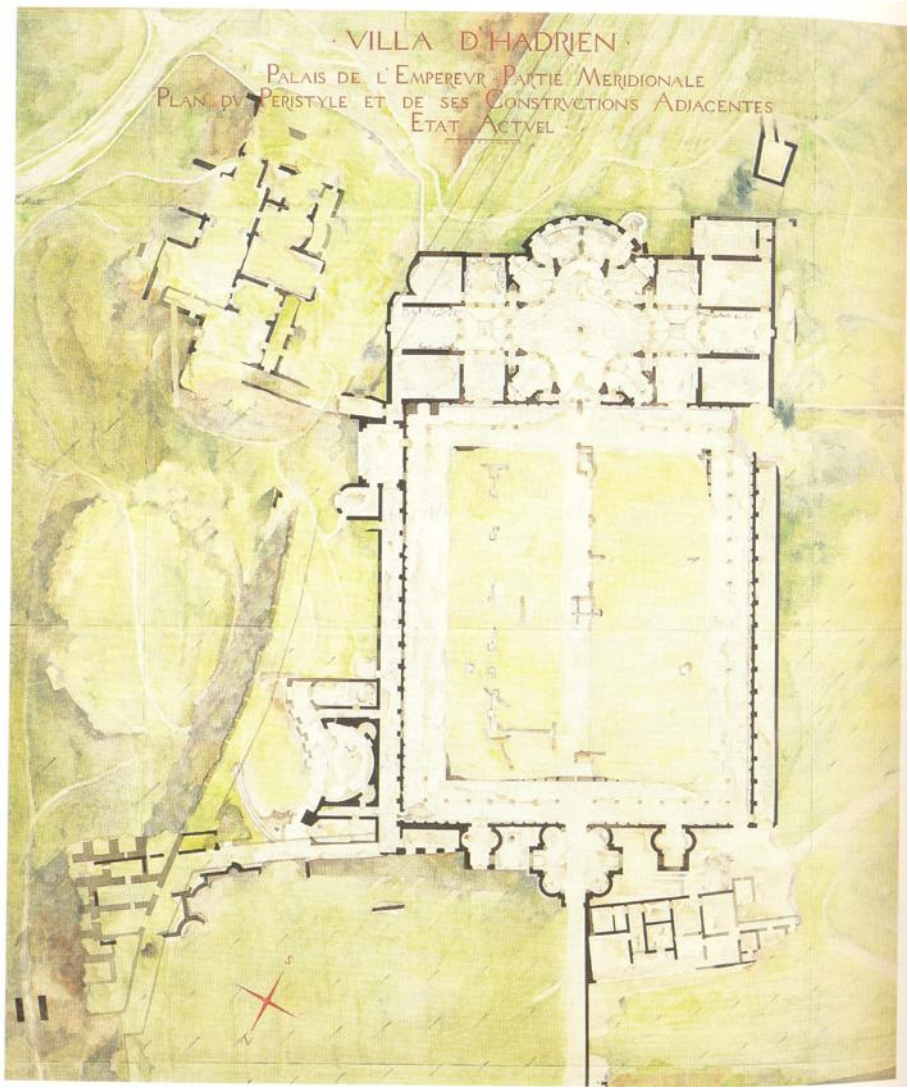

Fig. 4 – Map of the "Piazza d'Oro" by Charles-Louis Girault (XIXc).

The graphical documentation shown of the Piazza d'Oro is a result of the combination of upliftings with topographical methods using 3D laser scanning technology and photogrammetric techniques. It is worth

differentiating between the more generic architectonic uplifting and the more precise archaeological uplifting, fundamentally of the hunting-style friezes. In both cases the initial results are 3D virtual models that reproduce the real shape of the object with considerable precision. From these models, all necessary graphical documentation has been generated for the development of the different stages of research.

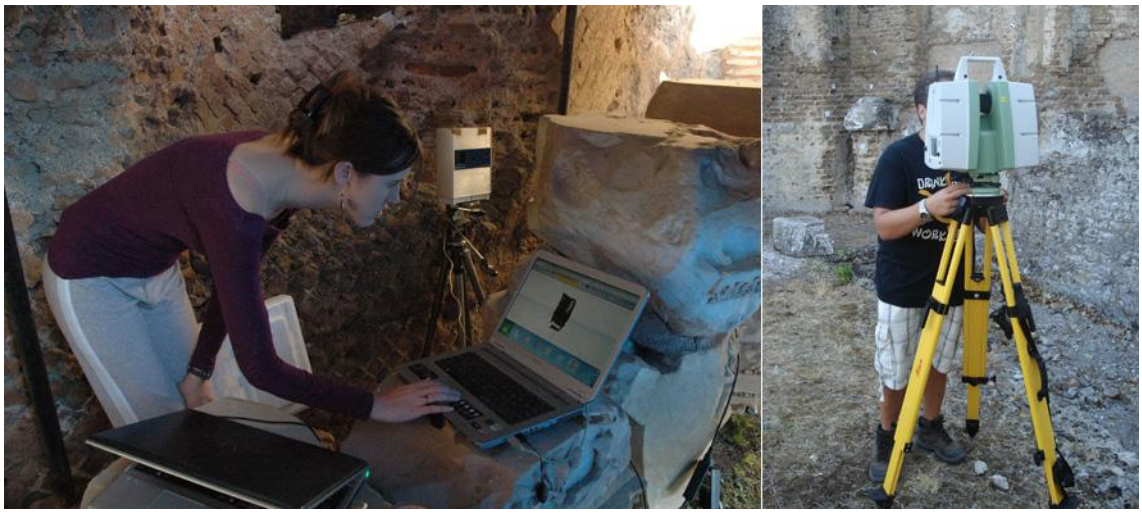

Fig. 5 – Left: Scanning of a frieze with hunting subject using 3D laser technology (April 2011), right: Uplifting of the Piazza d’Oro with Leica C10 laser scanner (September 2011).

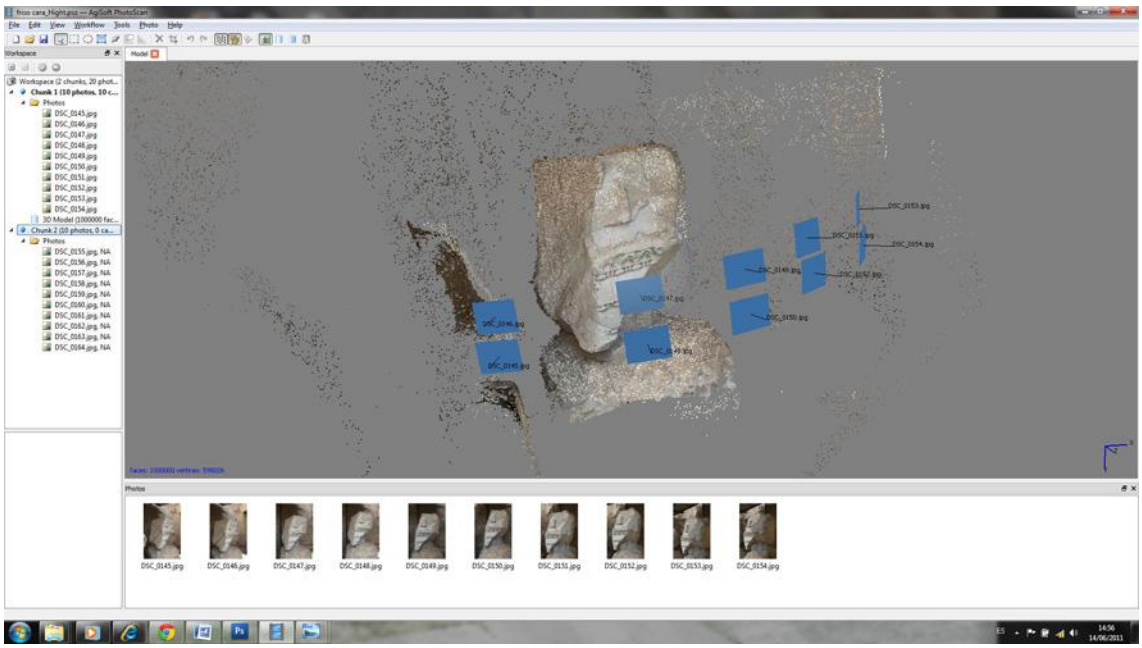

Fig. 6 – Model obtained by photogrammetry (2011).

In the case of the friezes, data collection was carried out using 3D laser scanning technology combined with photogrammetric uplifting techniques. Given its greater precision, the data obtained by scanning was used as basic documentation. Besides, it was ensured that this was the predominant tool used when uplifting those parts displaying decoration. Regarding those areas lacking in ornamentation, as well as those whose conditions were not optimum for the operational capacity of the scanner (distances, brightness …), they were

integrated using photogrammetric techniques. Photogrammetry turned out to be very useful in order to speed up times in those areas which did not require a high degree of precision. However, the photos had to be taken adhering to specific procedures which would enable them to be integrated subsequently in the 3D model. The result of the combination of both models was the generation of 3D virtual replicas of each of the archaeological pieces. Using these as a starting point, it was possible to produce a personalised graphical record, combining the most relevant plants, elevations and sections together with a schema of archaeological identification and a view in perspective where the section plans can be recognised.
On the other hand, the reading of the architectonic ruin was carried out using Leica C10 3D laser scanning. The uplifting was processed using "*Cyclone*" software, connecting the different point clouds until only one three-dimensional model was obtained. In this same application the floor plan was generated carrying out several horizontal sections on different levels on the cloud model, drawn as poly-lines. Processing its representation was topographical, taking on the irregular character of the forms of the ruin, lacking any defining architectonic lines. Three sections were carried out in this way, looking for a strategy that would enable us to obtain the maximum information possible without superimposing similar data. By allocating the elevation ± 0.00 m at the point of central levelling-off, the sections carried out were as follows:

- a + 0.10 (low plan) as base support at the level of the bases of the columns and skirting boards, the area where least was missing and with greater formal definition, with some partial reconstructions that helped us to understand the achieved profile.
- a + 0.50 (medium or archaeological plan) which reaches the starting mechanisms of the greatest possible quantity of factories, at the same time as enabling us to recognise all the spaces.
- a + 1.50 (high or architectonic plan) above the height of the former bases, reaching those emerging elements that are still standing or that were reconstructed at a later period of time.

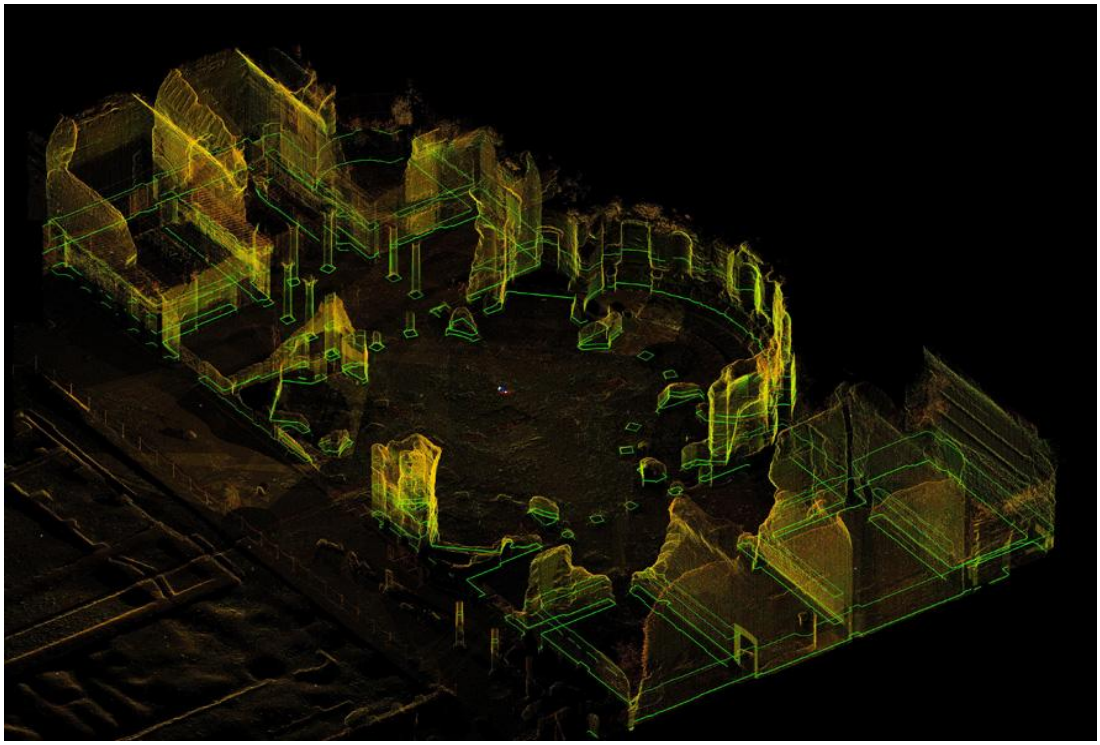

Fig. 7 – Screenshot of point cloud with sections on 3 levels (2011).

Once the plan of the factories was generated using these 3 level lines, the remaining surface information (relief, texture …) was added carrying out a screenshot projected over the plan with zero elevation. In this way the definitive plan of the uplifting was obtained, totally defined and of high precision and reliability, enabling us to carry out detailed studies during subsequent stages.

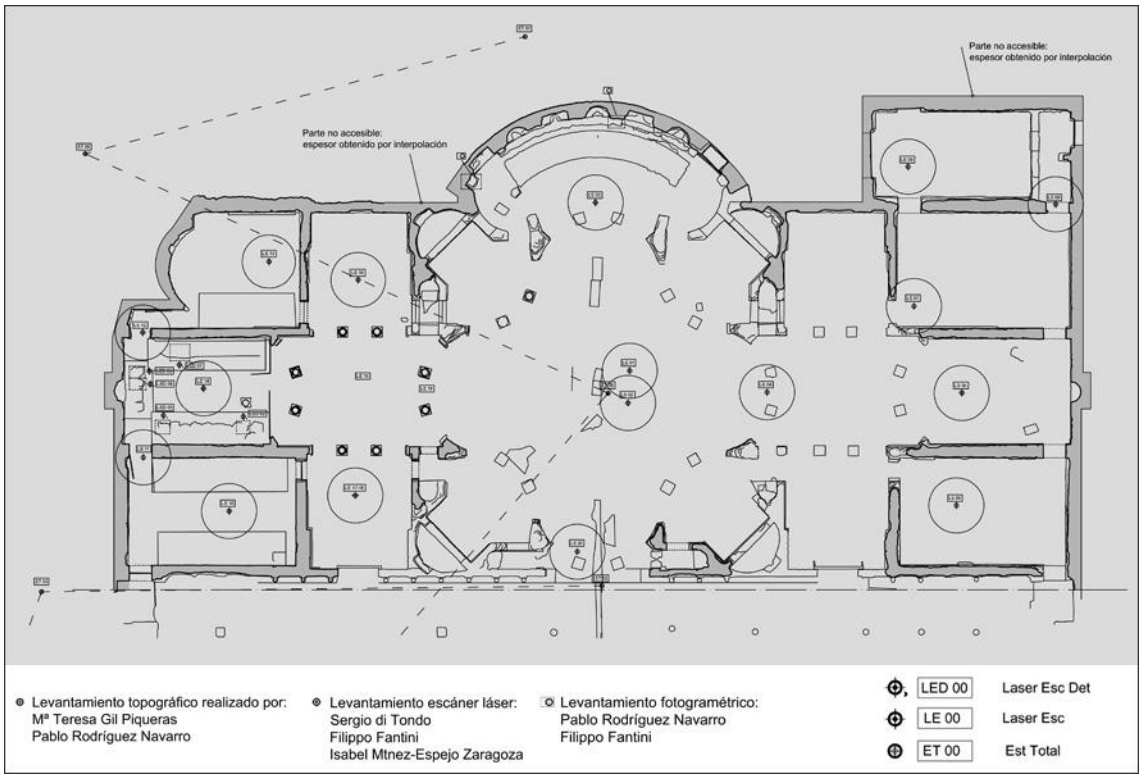

Fig. 8 – Image of the Piazza d’Oro plan as a result of developing the data obtained using different types of uplifting (2011).

Considering the complete model of the point cloud as a starting point, a 3D polygonal model was generated via the representation of subdivision surfaces. We endeavoured to obtain variable levels of detail, so as to register the prints of the architectonic elements in the ruin, with the aim of studying traces of the position of architectonic order in the elevations. With this criterion and on this second digital model the two main vertical sections completing the graphical documents of the basic uplifting were carried out.

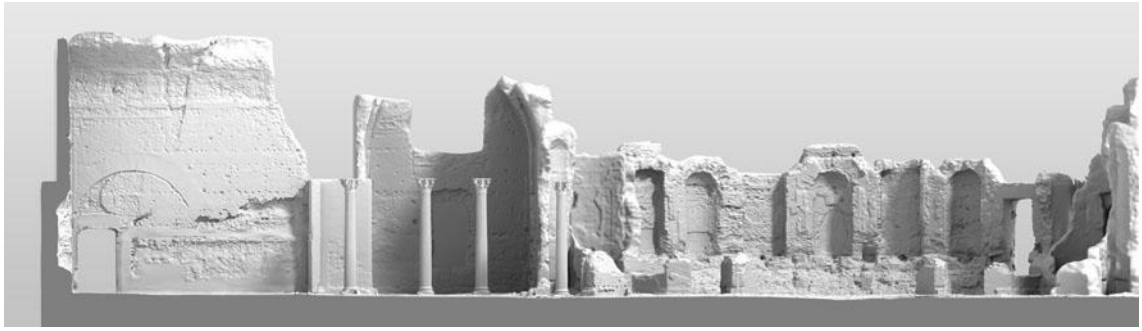

Fig. 9 – Render of a transversal section of the Piazza d’Oro, obtained from a polygonal model represented by subdivision surfaces (2011).

In a parallel and independent manner, a fragment of the architectonic order was restored from its remains. The proportion of the Corinthian order according to Vitruvius was taken as a reference. In accordance with this Canon, the columns were to have a total height, including base, shaft and capital, of 9.5 diameters (0.5 for the base, 8 for the shaft and 1 for the capital). However, assuming that during the Imperial period Vitruvius' measurements were applied with a certain degree of flexibility, it was confirmed that the Corinthian capitals of the Piazza d'Oro were slightly higher than the canonical ones, as was habitual in the cases of capitals with more complex decorations, unconnected to the Vitruvian model. Also the entablatures (architrave, frieze and cornice), decorated with a particular ornamental repertoire, had higher proportions than the Vitruvian one.

In any case, even when measurements show differences with respect to canonical proportions, they are almost exactly in fitting with Roman metric units. For example, comparing the lower diameter of the column's shaft with the Roman measurements (1 Roman foot = 295.6 mm), we can obtain that 1 lower diameter of the column = 442.404 mm /295.6 = 1.4966 ≈ 1.5 Roman foot = 6 spans = 1 cubit.

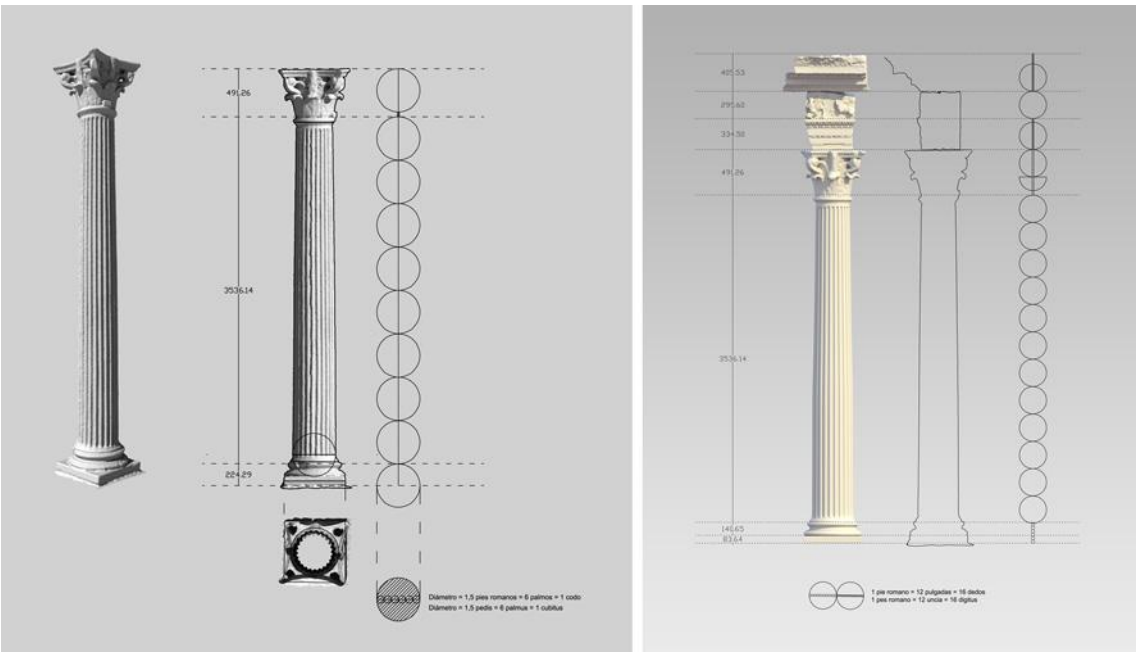

Fig. 10 – Left: Image of a Corinthian column of the Piazza d'Oro, obtained from a point cloud taken using architectonic laser scanning, right: Image of Corinthian module obtained from the combination of different scanned elements.

Restoration was carried out, in part, by means of virtual anastylosis, from the different preserved archaeological remains of pieces which made up part of the columns and entablatures. They were scanned and the 3D models thus generated were set up digitally on the Vitruvian standard. The remaining areas were restored using the element's theoretical volume, in order to obtain a complete fragment of the architectonic order, from the base to the cornice. The main application of this fragment will be its use, in subsequent stages, as a floating standard in the composite study of the architecture in interior elevations.

In order to identify the original location of the friezes' fragments, an examination of compatibility was carried out between the geometry of the pieces and that of the factories of the monument in horizontal projection.

The shape of the former ones was analysed directly in each of the graphical records. The geometry of factories was studied in the plan obtained during the uplifting stage.

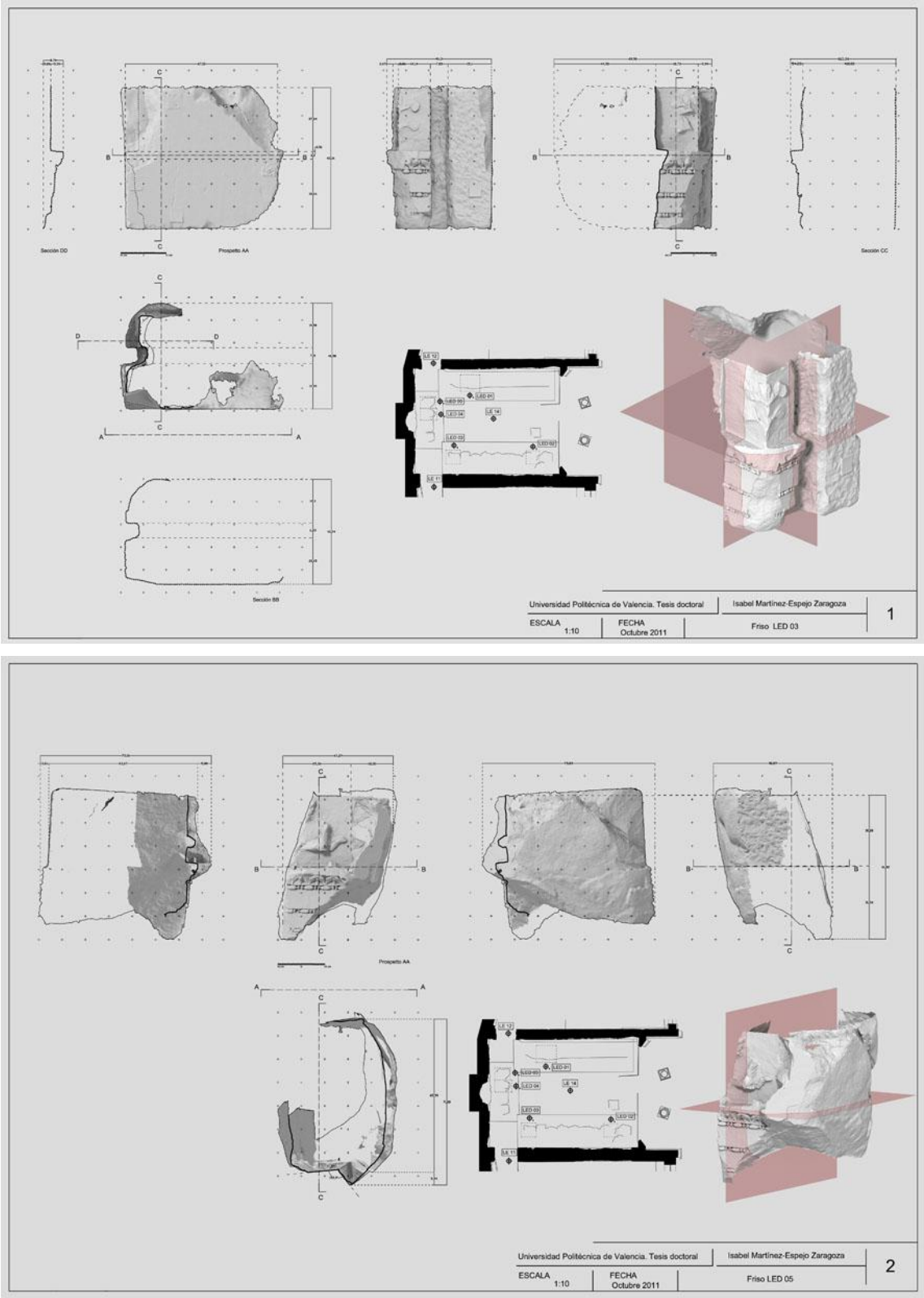

Fig. 11 – Images of graphical records 1 and 2 carried out on fragments of scanned friezes.

The complex nature of the plan's layout means that many of the preserved fragments of the friezes show multiple faces, forming different angles between themselves. In the cases in which remains of decoration are identified, the figurative compatibility of the subjects represented constituted a fundamental argument for identifying their location.

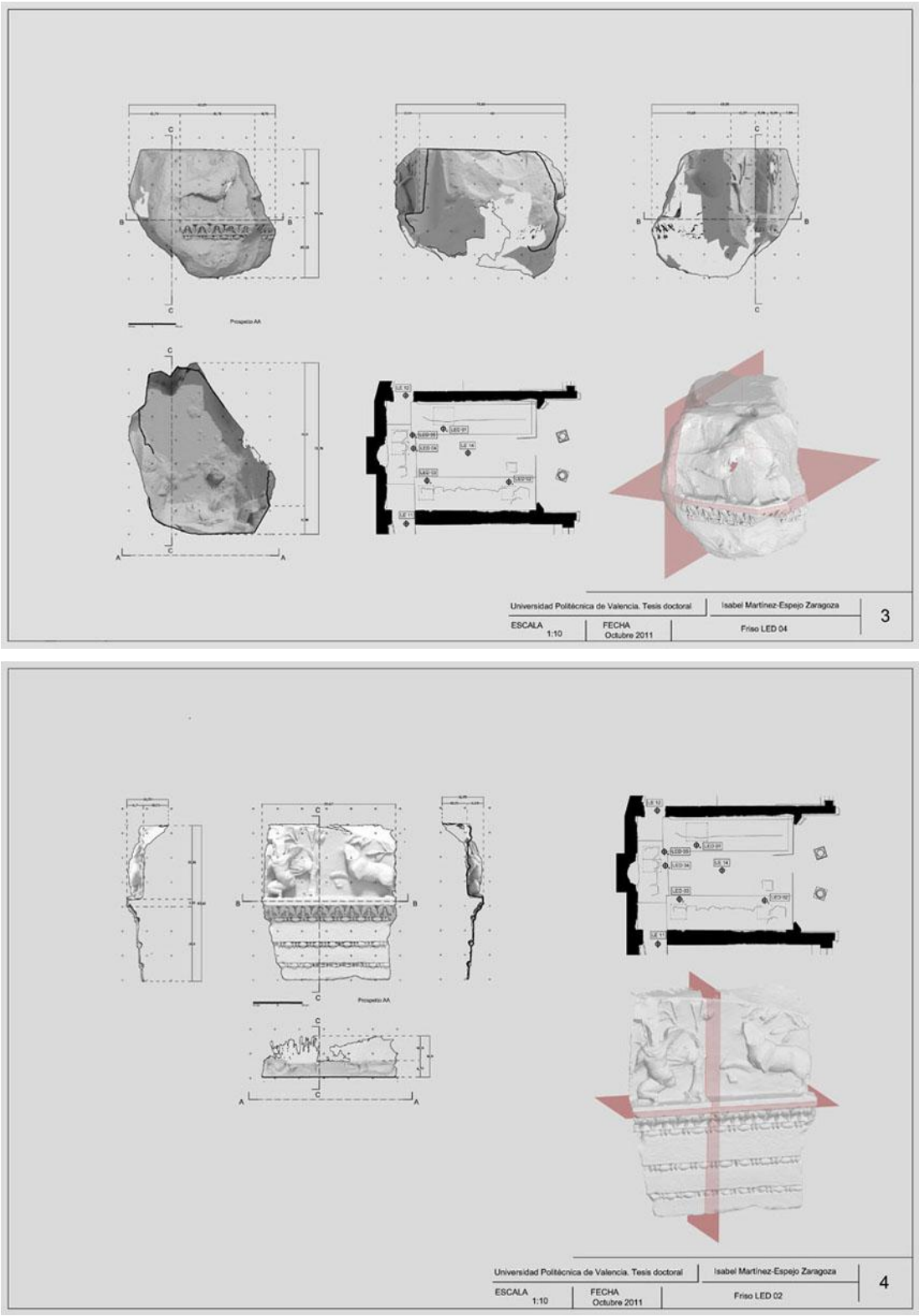

Fig. 12 – Image of graphical record 3 carried out on one of the fragments of the scanned friezes and image of graphical record 4.

The example piece (record 2) shows decoration on only one of its faces, and on the opposite face the surface is flat with a certain roughness, probably in order to allow it to be fixed to the wall. It can also be appreciated that the decorated face has a surface that is prepared to receive another adjacent piece that defines the starting mechanism of a non-orthogonal element.

This other example (record 3) displays decoration on its two opposing faces, which enables us to define the exact thickness of the exempt entablature. Furthermore, on one of the decorated faces it displays angles on its horizontal plane that allow us to deduce that this piece had one of its sides directly attached to the wall.

This frieze fragment displays angles such as so that it cannot be positioned on the plan. However the lower architrave was still fixed to it and was well preserved so that it was possible to carry out a virtual reconstruction of the complete order (record 4).

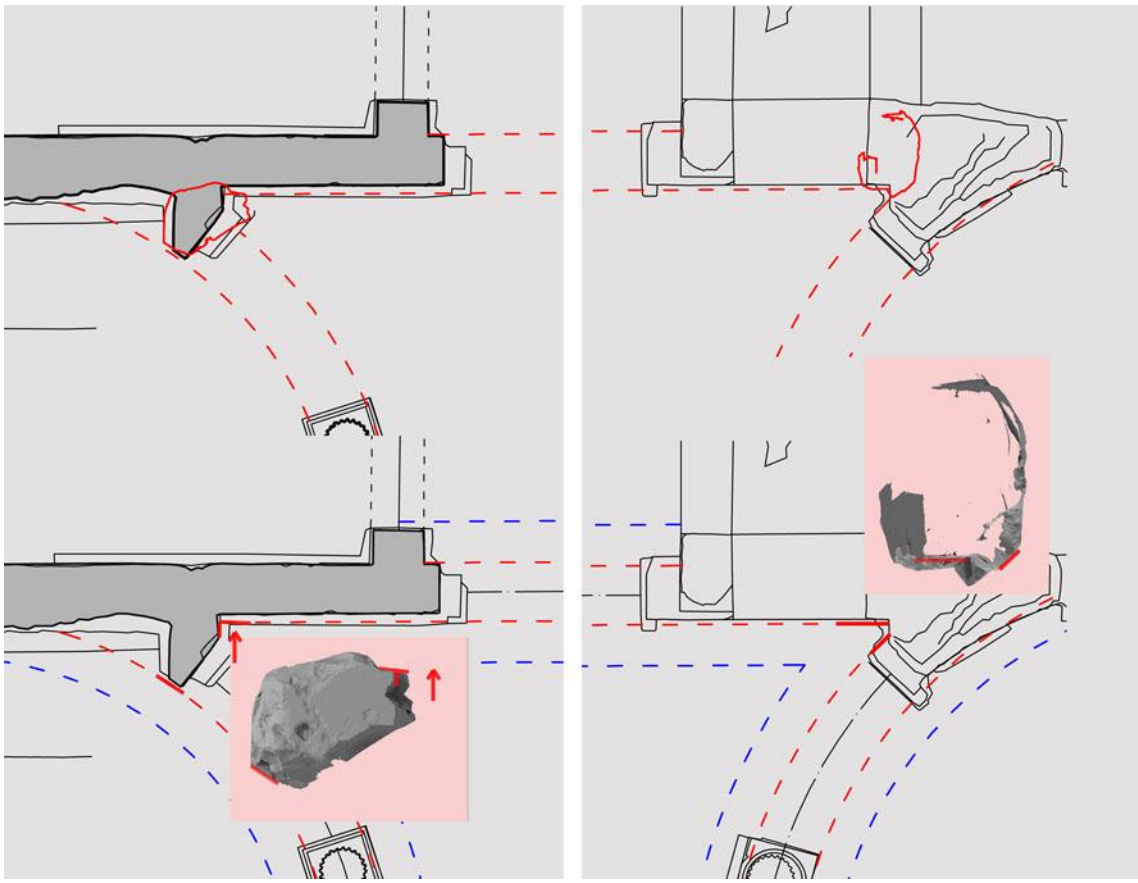

Fig. 13 – Images of the explanation regarding the hypothetical location of the pieces post-analysis. To the left, the LED 04 frieze, to the right, the LED 05 frieze.

Initial Results

According to the most conclusive archaeological studies, the maritime thiasus friezes were found to be located in areas where water was present. By reciprocal deduction we could assume that the friezes with hunting subjects were found located in areas where water was not present.

Combining the geometric arguments with the figurative ones the situation of two of the four friezes scanned in the April 2011 campaign could be identified.

The LED 05 frieze (face) has decoration on only one of its sides. The angle is coincident and it has one face prepared to support the piece which would continue forming the exact design.
The LED 04 frieze (corner) displays decoration on its two faces (always with the same subject matter) and the angles do not allow us to find the exact position given that we cannot find another similar angle in the Piazza d'Oro. Besides, the decoration finishes just at the point where it would join the wall.
Once the location of the piece is found, the frieze is placed in its exact position checking that the angles coincide both vertically and horizontally as well as with the outlines that are marked on the still-standing walls.

Summary

Thanks to the study being carried out, in-depth knowledge is being obtaining about the Piazza d'Oro with special attention being paid to the hunting friezes that adorned some areas.
The aforementioned study stems from a rigorous technical uplifting using laser scanning technology and 3D virtual models. By using horizontal sections this allows us to generate realistic planimetry on 3 different levels of the whole of the Piazza d'Oro and vertical sections of the current state.
More detailed documentation of decorative elements that have been structured in personalised graphical records is obtained. It has been possible to locate some elements in their original position in regard to their geometric compatibility with the whole plan.
Using these elements, a metric study of architectonic order is carried out via virtual anastylosis. Hence we can manage to lift a module of the order, obtaining vertical measurements that are comparable with the anchorage prints remaining on the walls and which enable us to reinforce the correct anastylosis.
It must be understood that these are the initial results of a piece of research that will finish, after a long study of all remaining documentation of the Piazza d'Oro and of all research carried out up to present date, with a virtual reconstruction of the whole, taking advantage of new technology in order to carry out more precise work with non-destructive techniques. It is also planned to carry out a structural study that will guarantee the proposal.

Acknowledgements

We gratefully acknowledge the "Soprintendenza per i beni archeologici del Lazio" for allowing us to carry out this research and providing us with all necessary material.
We should also like to thank Dott. Filippo Fantini for his continuous help and patience, providing us with extremely wide knowledge as regards the subject matter and without whom it would have been impossible to carry out this research. Thanks also go to Dott. Sergio Di Tondo for his collaboration and who, along with Filippo, carries out research on Hadrian's Villa in parallel to this one.
We are grateful to professors Pablo Rodríguez Navarro and Ma. Teresa Gil Piqueras for providing us with the data they obtained from the topographical uplifting they carried out. Without this the high precision of the study would not have been possible.

Last but by no means least, we would like to thank Leica for the loan of the C10 laser scanner, the latest model brought out by this company that has allowed us to obtain cloud point models, from which we have been able to obtain plans, sections … with a high degree of precision.
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Historic and archaeological itineraries for the discovery of Friuli during the Lombard period

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Abstract: The study is a year project funded by the Region Friuli Venezia Giulia. The area under consideration is quite broad and ranges from Gemona del Friuli up to Romans d'Isonzo. Thanks to the historical record, and in particular the Historia Longobardorum of Paul Deacon, the existence of at least seven castra located precisely in this strip of territory is known; the archaeological excavations have also brought to light several necropolis, some of them very extensive as, for example, that of Romans d'Isonzo. During the project, the classical methods of archaeological research (bibliographic and archival research, study of historical maps) have been joined to more technological methods (GIS, aerial photography and oblique aerial photography, UAVs, 3D reconstruction). The project was divided into several phases: the first focused on the bibliographic research, the examination and analysis of the ancient sources and historic cartography, the study of aerial photography and the use of remote sensing data with hyper spectral sensor MIVIS. For all the duration of the project several flights with ultra – light airplane were made to make oblique aerial photos, thanks to the cooperation with the Aeroclub of Ajdovščina in Slovenia.
This part of the project is mainly aimed at the identification of traces of anomalies on the ground that were analyzed later by reconnaissance on the field. We also used the UAVS, unmanned aerial vehicles, as a supplement to the study of aerial photographs.
The next phase of the project consisted in putting all this data in a GIS. These data were combined with a DEM on which it was possible to perform various spatial analysis to reconstruct the ancients roads system and suggest the development of settlements in relation to cemeteries, the only known proof of the presence of the Lombards in Friuli.
The final part has focused on the 3D reconstruction with a specific software of ancient landscape in two test sites, for which we have more information from historic cartography and excavations, as well as pollen analysis that allowed to have more precise information concerning the vegetation cover in the area.

Keywords: GIS, aerial photography, 3D landscape reconstruction, UAV, Spatial Analysis.

Introduction

The project aims to rebuild the landscape, the ancient road system and the anthropic development in the northern part of the ancient Lombard Duchy of Friuli, which had as capital the ancient city of *Forum Iulii* (Cividale del Friuli).

The project was divided into several phases:

- The first focused on the bibliographic research, the examination and analysis of the ancient sources and historic cartography and the study of aerial photography.

- The second consisted in putting all this data in a (FORTE 2002) and doing some spatial analysis.
- The final part has focused on the creation of a WebGIS and a 3D reconstruction of ancient landscape in two test sites, is scheduled as soon as all the data will be collected.

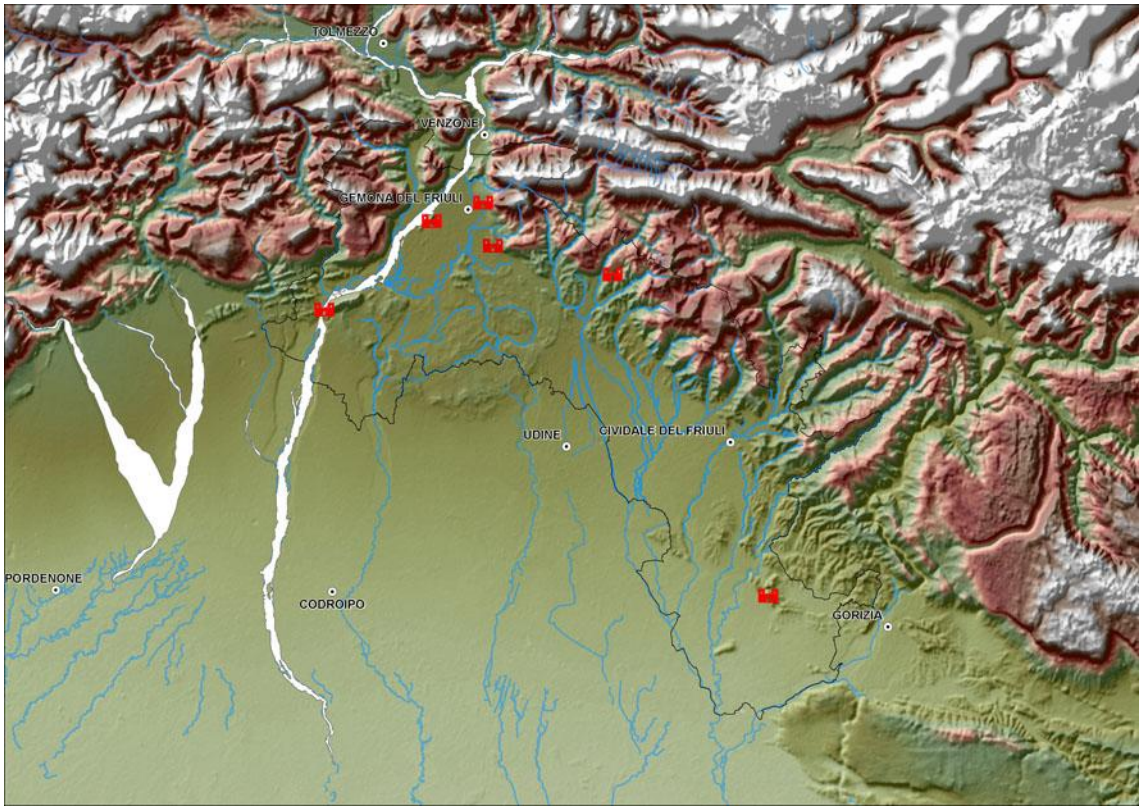

Fig. 1 – The position of the *castra* in the territory of Friuli.

The Duchy of Friuli, one of the great territorial Lombard duchies, was the first to be established. The province of Friuli (*Venetia*) was the first province of Italy to be conquered by the Lombard under Alboin in 568 A.D. Before continuing on to penetrate Italy further, Alboin placed the government of the district under his nephew Gisulf I, who was allowed to choose the *faras,* or noble families, with which he wished to settle the land. The capital was, as said, Cividale del Friuli, founded as a roman *municipium* by *Iulius Caesar* in 50 B.C. with the name of *Forum Iulii*.

In 568 A.D. the city was the first major centre occupied by Alboin's Lombard invasion of Italy, then part of the Byzantine Empire. After the Lombard were defeated by the Franks, (774 B.C.), *Forum Iulii* changed its name to *Civitas Austriae*, Charlemagne's Italian "City of the East".

The research was started by basing it on *Paulus Diaconus*' *Historia Langobardorum* in which is written about seven *castra*. In the portion of territory chosen for our research there are 6 of them, *Cormones, Nemas, Osopo, Artenia, Reunia, Glemona*, as well as the capital. All these *castra* and all the necropolis found during excavations from the 1800 century till our days were put into a GIS. Each point has an attribute table regarding all the important information about the site, such as the town where it was found, how many graves, what kind of tools or jewelers was found, etcetera.

The first part of the project

The first part of the work was about the study and the analysis of several aerial photographs. Some of them are in the cartographic office of the Region, others in the Istituto Centrale per il Catalogo e la Documentazione (Central Institute for the Catalogue and the Documentation – ICCD) in Rome. We were able to analyze photos from 1943 to 2006, collecting a huge amount of data, 271 photos. It was possible to recognize and identify several traces of anomalies on the terrain. The use of aerial photo, in function of the historical archaeological landscape, has been behind a consistent and documented tradition (CAMPANA and REMONDINO 2008; MUSSON et al. 2005; PICARRETA 1987; PICARRETA and CERAUDO 2000; WILSON 2000). Photo interpretation does not mean the reading of aerial photography because it is not a simple observation, but a real process of analysis and synthesis that allows to deduce some aspects of what you can't see and it must make sense of all the information obtained through the diachronic reconstruction of everything that is still visible today of ancient landscapes. For this reason, in our project, the photo interpretation was integrated with the study of archival records and historical maps, so that it was possible to have a clear idea and the fullest possible information related to the portion of the Region examined.

Fig. 2 – An example of an anomaly of a possible road. The second image shows the digitalization of the traces in the GIS.

Each photo was georeferenced on a GIS and each trace was digitalized to create a complete database. In some case it was possible to recognize the same trace in different photos of different years but unfortunately most of them have not been sawn during the surface prospecting done in the area, due to the high urbanization after the earthquake in 1976. Otherwise interesting results have been achieved in searching and identifying the traces of possible roads to try to reconstruct the ancient road network in the Region.
In addition and as a completion of this work several flights were made with an ultra light plane to produce oblique aerial photography.

Fig. 3 – The ultralight used for oblique photos.

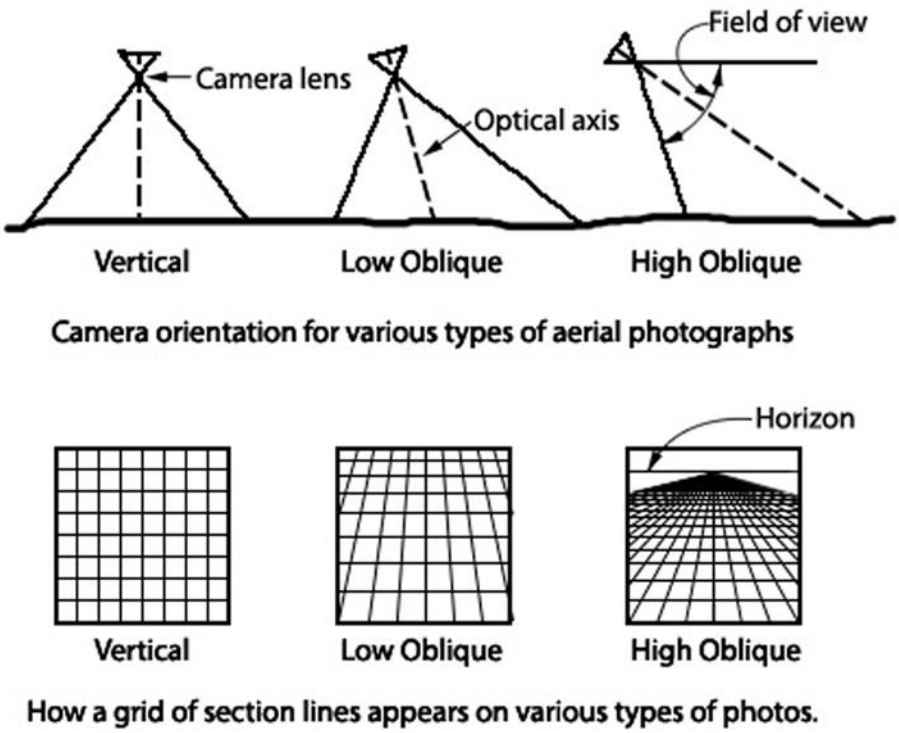

Fig. 4 – Scheme of the difference between vertical and oblique photographs from airplanes.

Photographs taken at an angle between 5° and 85° are called oblique photographs. If they are taken from a low angle earth surface–aircraft, they are called low oblique and photographs taken from a high angle are called high or steep oblique.

All the flights were done with the collaboration of the flying club in Ajdovščina, Slovenia. Only after the 29th December 2000 decree from the President of Italian Republic it has been possible even in Italy to take aerial photography from private airplane without incurring in any kind of penalty.

During the flights it was possible to see different kind of traces. Every anomaly found during the flights was photographed and a form with basic information such as weather, duration of the flight, how many photos has been taken was compiled and the GPS coordinates of the point with a portable GPS device, in correlation with the airplane GPS were taken.

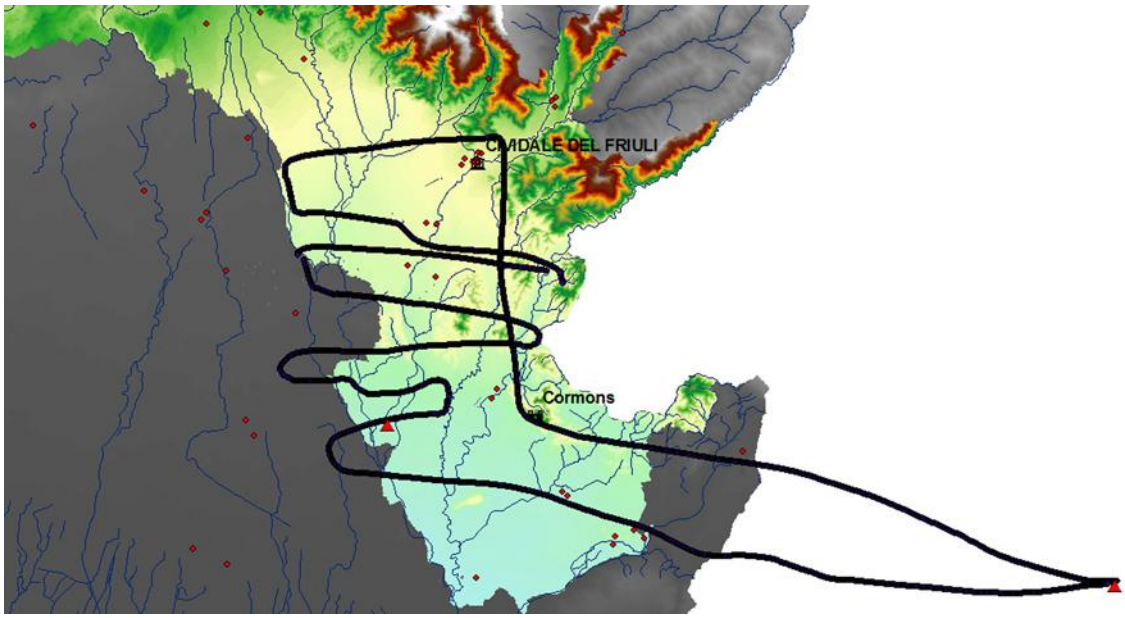

Fig. 5 – The route of the flight taken with the GPS and put into the GIS, the blue points, and with the red triangle is indicated the exact point taken with a GPS of the location of the linear trace.

The most interesting traces are the ones near Romans d'Isonzo that shows circular traces in an area near a very important necropolis and another one that shows a linear trace near Cormons, *Cormones*, one of the *castra*, and which may refer to an ancient road that we know had to pass in the area.

Fig. 6 – The two different anomalies discovered during two of the flights done over the Region: the first regards circular traces near Romans d’Isonzo, the second a linear trace near Cormons.

The UAV

As a research on new technologies an Unmanned Aerial Vehicle was tested trying to see if it could be useful for our purpose. In recent years the use of UAV systems had an increase in archaeological research, especially with the use of multi rotors UAVs that allow a better stability and so an improvement in taking pictures (BENDEA et al. 2007; CAMPANA et al. 2008; CHIABRANDO et al. 2009; EISENBEISS and SAUERBIER 2010; EISENBEISS 2008; EISENBEISS 2009). Using these systems, however, involves rather high costs, especially with ready-to-go systems as, for example, Microdrones aircraft, because it’s given, in

addition to the aircraft, also the radio control and the notebook, all the telemetry software, the GNSS and the altimetry sensors; on demand, it's possible to have also all the instruments for the shooting. It allows to take vertical photos from a low height and it's used especially for the photogrammetry.
The system is the Gaui quadcopter 330X-S, a low cost UAV that has a payload up to 700 grams and has also the possibility of future implementation with other useful instruments like the GNSS system, the support for some kinds of video and photo cameras and it has also a kit to increase or decrease the length of the arms, a way to improve stability in flight.

Fig. 7 – The GAUI quadcopter.

The quadcopter was equipped with high quality three-cell LiPo battery pack (Lithium-ion polymer batteries) that provides about 20 minutes of flight range, a second battery has been purchased to increase the time of the shooting. The camera, compact Canon IXUS 85 IS, was placed on a support with a specific servos that allows rotating the camera to 90° relative to the terrain and the foot of the quadcopter were changed, replaced with longer support for an easy take off and landing without the risk that the camera could touch the ground.
The choice on the brand of the camera has been dictated by the possibility that most of the Canon have to use open source software, CHDK, which allows many applications to be added to the camera. The software gets loaded into the camera's memory upon boot up, either manually or automatically, using the microprocessor that controls the camera and it performs no actual change on the camera. The software allows having an enhanced way to capture images in RAW format, as well as JPEG, and video. It's possible to increase the time and length, with an augment of compression's options. For this project the software was used for providing the opportunity to shoot in sequence with an interval time of 5 seconds, from remote: this function was useful for shots from the quadcopter because in this way it was enough to activate the program and, during the flight, the camera continuously took photos without the intervention of the operator. The result was the achievement of hundreds of photographs covering, also redundantly, the whole area of the excavation: in this way it was then possible to select the best photos without the risk of having lack in the documentation of the excavation.
Our purpose was to test a low cost system for the creation of a 3D mesh regarding the archaeological sites. Unfortunately no one of the Lombard sites in the regions were available for taking the picture, so we tested the UAV in two roman sites, the first is the late roman city wall in Aquileia and the second a heat in

Dolegnano. For this work were used the free Microsoft software Photosynth and two open source software, Photosynth Toolkit and Python Photogrammetry Toolbox GUI, created by Alessandro Bezzi of ArchTeam, for the creation of the three dimensional cloud of points extracted from the reprocessing of the photos, and for the creation of the mesh from these 3D points was used the open source software MeshLab, developed by the University of Pisa (BEZZI et al. 2010; BEZZI et al. 2009; MOULON and BEZZI 2011).

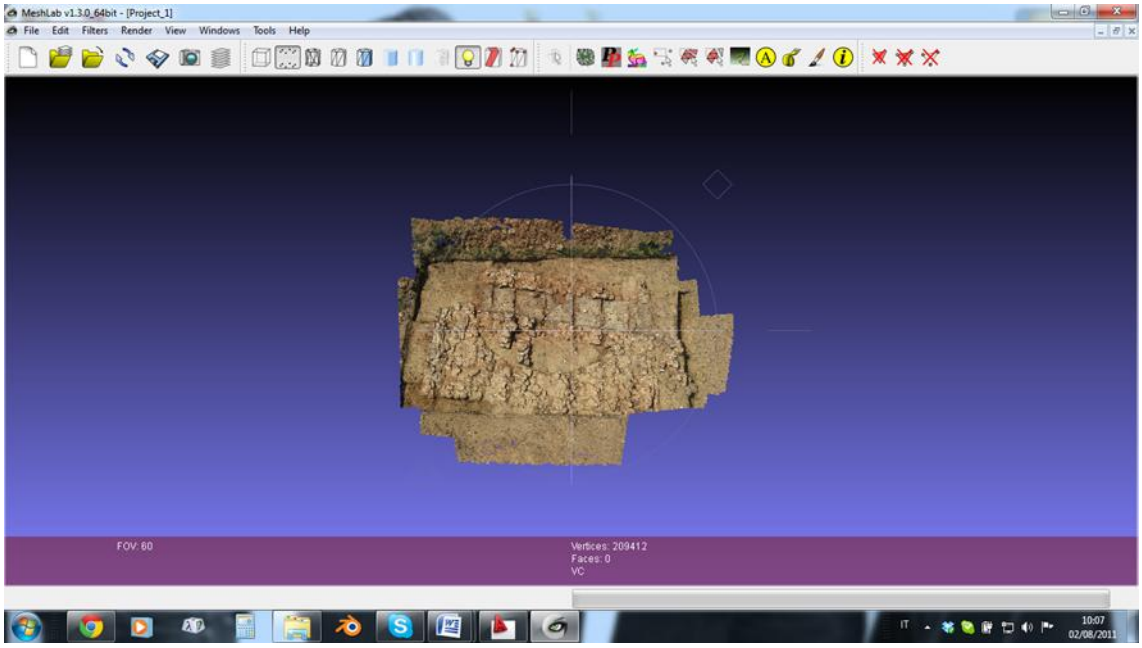

Fig. 8 – The 3D point cloud of the site of Dolegnano (UD) created with Python Photogrammetry Toolbox GUI and opened with Meshlab.

The experiments made on the two archaeological sites taken as sample gave interesting results, but require further investigations and testing. The idea of this work is to continue experimenting with the software Python Photogrammetry Toolbox GUI on other archaeological sites in the Region, perhaps even more complex then these shown in this article. Moreover, MeshLab gives the opportunity to scale the entire model of 3D cloud of points with the points taken with the total station during topographic surveys, transformed into 3D points with open source software like Blender, for example. It was noted that targets well visible, scattered in a consistent manner to cover the entire surface of the excavation, are well identifiable in both images and 3D models, so the intention is to try the MeshLab tools to scale the entire model created on the points registered with the total station. In this way there is the hope of having a processed result that is not an end in itself but can be useful and usable during the analysis and study of the excavations.

GIS and spatial analysis

During the Roman age, Friuli Venezia Giulia was crossed by several *viae Publicae* and *viae Vicinali* which served as connections between more important roads. Along the flat land strip from west eastwards we can identify two important roads: via Postumia and via Annia. Via Postumia, built in 148 B.C., crossed all Gallia Cisalpina from Genoa to Aquileia. As a matter of fact, according to *Tavola Peutingeriana*, the road ended in Oderzo (Opitergium) and its extension as far as Aquileia appears rather uncertain. Via Annia was the most

important consular route: it linked Aquileia to Rome; it had been built approximately in the middle of the second century B.C. and it is described in the *Tabula Peutingeriana*, in the *Itinerarium Antonini* and in the *Itinerarium Burdigalese*. Via Claudia Augusta or *Via per Compendium Concordia Noricum* linked Concordia Sagittaria to Codroipo (*Ad Quadrivium*), getting over the Tagliamento at Pieve di Rosa: in Codroipo it probably intersected the Postumia, heading then northwards as far as the station *Ad Silanos* where it came out onto the Iulia Augusta.

The four roads leading from North to Aquileia, across the Alps were:

- via Iulia Augusta, mentioned in both, Itinerarium Antonini and in Tabula: it led from Aquileia northwards up to the confluence of the Tagliamento and the Fella, following an almost straight route; there it was divided into two roads:
- a road towards *Aguntum* (Lienz) passing through Zuglio (*Iulium Carnicum*), then over the Alps through Passo Monte Croce;
- a road which nearly reached Klagenfurt (*Virunum*) passing along the valleys of the Tagliamento and the Fella and through Tarvisio;
- the fourth road led from *Virunum* to *Forum Iulii* and further to Aquileia, getting over the Alps by the Passo del Predil and along the valley of the Natisone.

We should also mention the roads leaving Aquileia eastwards, the via Gemina and the road linking Aquileia to Lubjana (*Emona*).

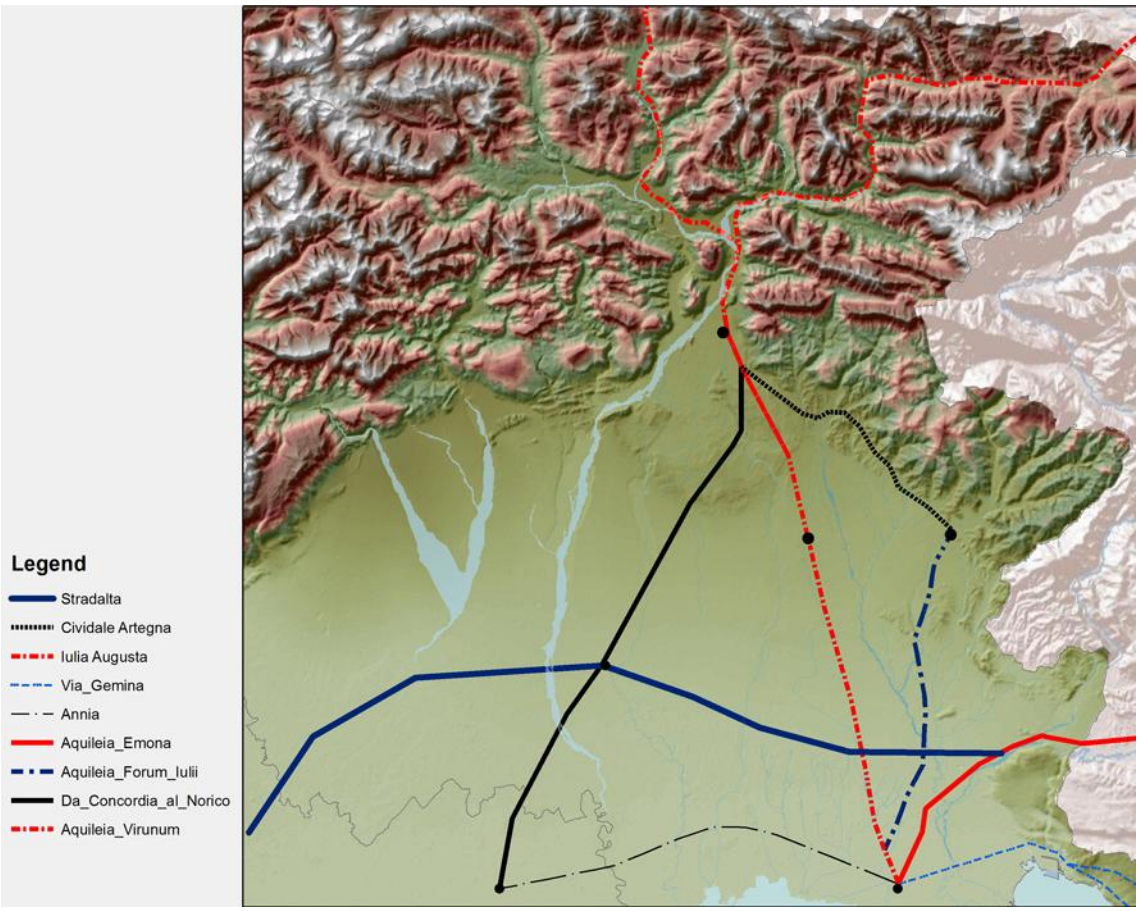

Fig. 9 – Ancient road network in Friuli Venezia Giulia.

In the area of our project, which extends between Gemona and Romas d’isonzo, there are traces of the existence of almost three routes: they have to be identified as routes of the Roman period, still used during the Middle Age, mainly after the destruction of Aquileia, which was considered as a landmark: this caused the shifting of traffic to other towns as to Cividale, Udine and Gemona: the last one became an important junction for commercial exchange because of its strategic position at the access of the Alps.
The last stage of this research aimed to assemble and work out all the so far surveyed data. Our attention fixed on the attempt for reproducing local traffic during the Lombard period.
For answer this question we carried out two different studies: a cost surface analysis and a line of sight.
With reference to archaeology the cost surface analysis assesses the energy consumption of a person transferring from a point to another; this kind of analysis allows us not simply to evaluate distances, but also to reproduce roads and tracks within an ancient landscape. A reliable simulation of this kind will supply us with the interpretative models in order to identify territory settling systems and topographic interrelations between sites. A line of sight or also a view shed analysis allows us to calculate the human visual field on the basis of the morphologic and environmental characteristics of the territory and site spatial interrelations within the landscape.
Before explaining the methods we used to get the results, I would like to fix our attention on the concept of model and explain what DTM means.
By model we mean an instrument used to reason, discuss, confute and make predictions. Science bases on models since they are practical representations of a simplified reality which trends to evolve by its own nature.
Cartography appears to be a very good sample of model: it represents the geographic reality of a precise culture at a given time, it uses symbols and has a specific function.
The model used in the present analysis is a mathematic model: its creation consists of a series of variables to recreate the landscape and to simulate the environmental conditions. In order to build it, we used a DEM (Digital Elevation Model), which allows us to survey the altimetry of a site.
First we carried out a GIS of the area by placing the sites of interest – as castles and necropolis – and traffic marks.
The second step provided the creation of a DTM with a 5m resolution. For create the DTM, we have used a specific program, written in Visual Basic language, this program extract from file DAT of the digital cartography only the natural elevation points without the anisotropic elevation point (for example the elevation point of the highway or a top of the bell tower).
With reference to this site part, we added the variables which allowed us to get the cost model. Among the most important variables which we considered as rather important we would mention:

- Slope. This variable greatly influences the route: as a matter of fact in the past the use of carts did not allow the construction of roads along steep slopes and even grounds were preferred.
- Altitude above sea level. With reference to slope, this variable is less important but a too high altitude may substantially influence travelling costs. We must consider that we could detect even flat grounds at three thousand meters, and therefore the cost would result very low when referred to slope, very high when referred to altitude: in addition at lower heights the climate is surely milder for longer times.

- Hydrographical network. We have considered two different rivers type, depending on the water capacity and the river bad. For example as to the specific, we did not consider the rivers since the Tagliamento shows a gravely bed though a limited surface discharge and consequently its crossing resulted very difficult in the past for the hypothetical carts.
- The line of sight. The castles had the function of control of the territory and therefore also on the road. We have calculated the view shed analysis of the castle mentioned by Paolo Diacono in the Historia Langobardorum. We added about 10 m that is the height of a tower increased by 1.65 m (average height of a man at the time) to the altitude registered on the site. We obtained two differently coloured zones: the former indicated the visible areas, the latter the non visible ones.

We have reclassify the variables for standardize the data, the choice of the range values is arbitrary and we have choice the range 0 to 10 where 0 is the minimum value and 10 is the maximum value. The variables were entered into the model by giving a weight to each one of them. The slope is the variable with the greatest weight, then the rivers, divided according to their water flow and the difficulty of their crossing, The variable with minor weight is the analysis of visibility. We have used an anisotropic cost model where the cost dependent on both the direction of travel and the attributes of individual map cells. The results is a Gaussian equation, where the slope is major or minimum of the 45 degree the cost tend to infinity.
For creating the cost model we use the spatial analyst extinction of the software ArcGIS version number 10. We have use Model Builder for create a weight model, the cost surface model and the path distance.

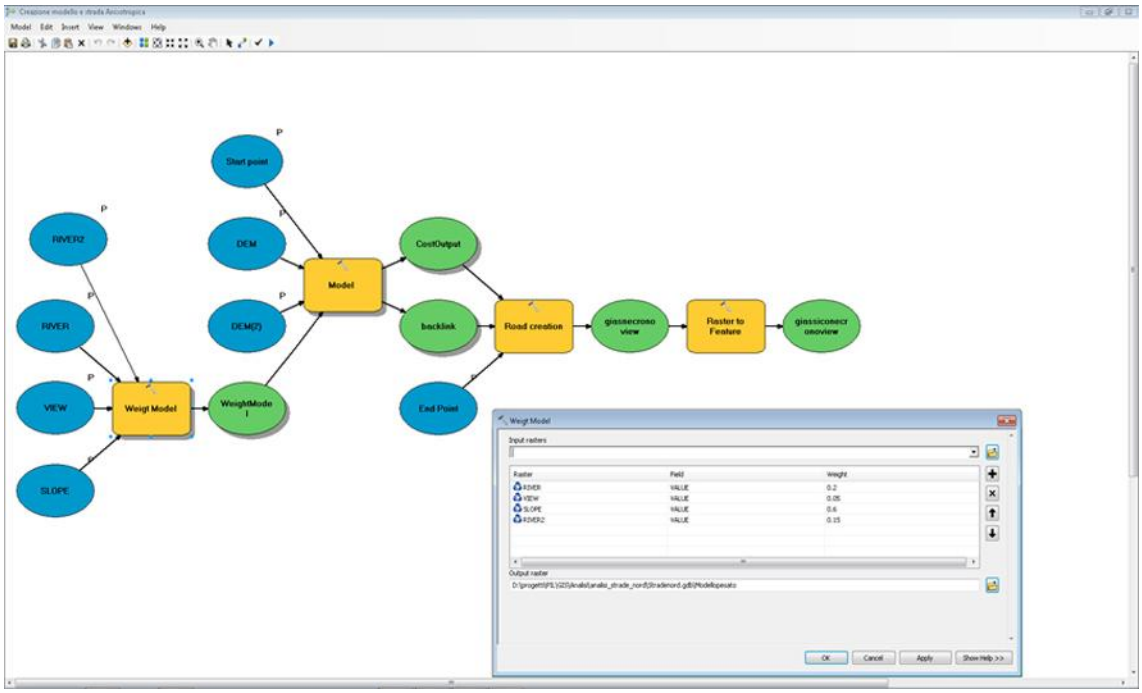

Fig. 10 – Model Builder.

For the first reconstruction we decided that our road originated in Cividale, we created a cost weighted from this site; it is characterized by the creation of a buffer zone of different colors which show the various travelling costs from Cividale towards the surrounding area. After getting the travelling costs of every pixel and having fixed the road starting point and the ends located at Gemona and Romans d'Isonzo, we were

able to create our “road network”. The calculator marked out a line which identified the site where the costs to get over and to build a road are cheaper.

We have compared the roads reconstructed by the computer with the hypothetical road network reconstructed with historical and archaeological studies by two important archaeologists: Luciano Bosio and Mario Brozzi.

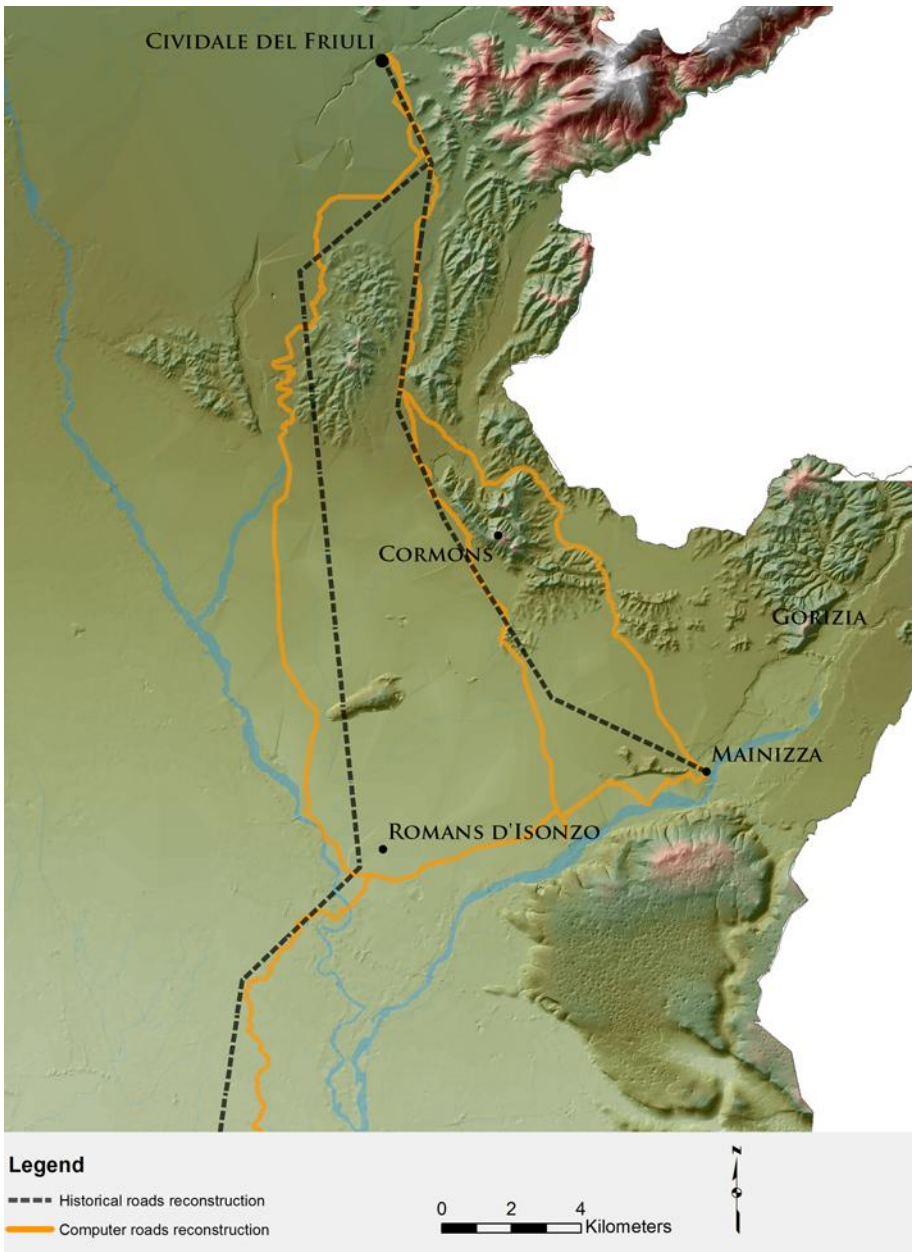

Fig. 11 – The overlapping between historical reconstruction by Mario Brozzi and the roads created with the GIS.

In the figure number 12 is possible to see in a light color the road reconstruction by the computer compared with the roads reconstructed by Mario Brozzi, is possible to see the overlap between the road that led from Aquileia to Cividale. In addition, especially for the road that goes from Cividale to Gemona we also identified through aerial photos interpretation some possible roads anomalies that overlap with the road reconstruction.

The second reconstruction is the road Concordia Artegna. The computer road is very different respect the road reconstructed by Luciano Bosio, but is very similar to the road represented in a map of 1820 century.

Fig. 12 – Overlapping between the traces seen on the aerial photography and the reconstruction with the GIS.

All results and data collected, will be inserted into the WebGis created by Emanuel Demtrescu with open source programs. In this WebGis it will be possible to download the track for GNSS car navigator.
In this moment we are working to create a prediction model, this model will be created for answer a specific problems: In our region we know where the Lombard died but we don't know where they lived. For create this model we will use a lot of variables: slope, number of necropolis and castles into the territory, distance of the river, elevation, sun exposure, the road network. This model will be created with the commercial software, but thanks at the help of a researcher Augusto Palombini of CNR in Rome we will make a similar work with a open source software. We hope that this work may provide new reading to better understand the territory and the history of Lombard.

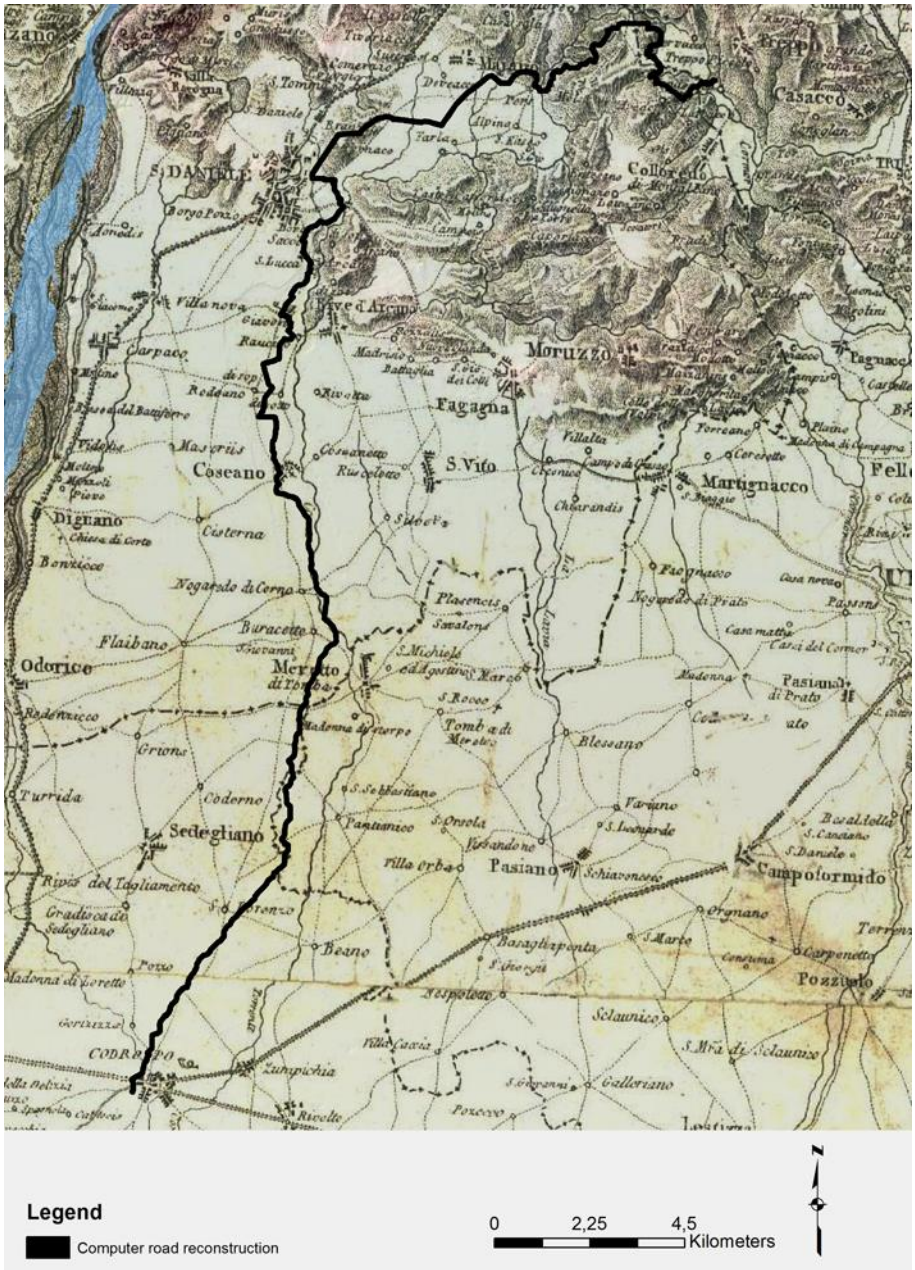

Fig. 13 – Overlapping between the 1818 cartography and the road reconstructed with the GIS.

3D reconstruction of the landscape

The final part of the project will be focused on the reconstruction of the landscape (PESCARIN 2009) during the late ancient and early medieval sites in two samples sites, for which we have more information and archival data. To achieve this reconstructions historical maps and documents of excavations will be used as well as pollen analysis which provide more detailed information in relation to the vegetative cover in the two selected areas. The site chosen are the Lombard necropolis of Romans d’Isonzo, which were recently re-opened for excavation after several campaigns that have taken place since the late ‘80s until 2007 and the necropolis of S. Martino di Remanzacco, investigated until 2009. All the archival data will be used in a specific cartographic software that will generate the 3D reconstruction of the ancient landscape with a good approximation.

Fig. 14 – Two examples of what is possible to create with the 3D software Visual Nature. The first image was made by Jonathan Rothwell, the second by Marco Gualdrini, both freely downloaded from www.3dnature.com.

Acknowledgments

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and Società Archeologica Friulana of Udine for permitting to do the flights with the UAV over the two archaeological sites and to use the documentation, and, last but not least, Dr A. Bezzi for his kindness and his willingness during the testing of the open source software Python Photogrammetry Toolbox GUI.

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Prerequisites for Find Density Analysis

Analysis of Survey Data from an East Andean Region

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Abstract: At a regional scale, find density analysis based on survey data is often applied to reconstruct settlement patterning. However, this is by no means a trivial task because often the finds recovered during the survey are not a random sample of the initial distribution. This is shown by analyzing the shovel probe and surface collection data from an East Andean region in Ecuador. In the Quijos and Cosanga study area, the spatial distribution of the finds recovered during the survey depends both on the initial artifact pattern and the post-depositional filtering processes. Attempts are presented to assess the impact of geological filters like erosion or flooding as well as bias due to the survey methodology. The test pit data recorded during the survey project can be used to check the assumptions underlying any find density analysis. However, the results are quite discouraging, because many items on the prerequisite list for find density analysis are not fulfilled and our correction approaches failed. It seems that additional data is required for reconstructing the initial find distribution in a consistent way.

Keywords: Survey, post-depositional filtering processes, find density analysis, correspondence analysis.

Introduction

The Quijos and Cosanga study area is located in the eastern flanks of Andean Ecuador (Fig. 1). This area was selected by Andrea Cuéllar for a survey project in 2002 (CUÉLLAR 2009). Cuéllar subdivided the area into collection units, generally no larger than one hectare. Surface collections were the preferred method but due to high density of vegetation in the region, most collection units were surveyed by shovel probes. The survey data available on the web (CUÉLLAR 2010) include only collection units with finds, i.e. 651 surface collections and 1471 shovel probes with sherd counts as well as 32 collection units surveyed by sections or a combination of surface collection and section. Botanical samples were recovered by Cuéllar's team from 31 1x1 m test pits, and another 15 2x1 m pits were excavated for stratigraphic tests.

In his PhD dissertation, Alden Yépez (YÉPEZ 2008) proposed a new ceramic typology for the pottery sherds recovered from the survey project. Each of the types was assigned to one of four phases based on the sherd quantities in the test pit layers. The four phases cover roughly the years 300 BC to 1600 AD. 23,915 sherds recorded in 2,154 collection units could be assigned to one of these phases. Initially, this data set seemed to be a good choice for applying an improved method for find density analysis due to the large quantity of ceramic data.

The find density analysis published by CUÉLLAR (2009: 43–53) is based on map distances and a chronological framework consisting of three periods only. Steep slopes exceeding 25% prevail in the study area, so the effort required by a pedestrian to cover the distance between any two points in this region may

deviate considerably from that on flat terrain. For this reason, we think that a method based on least-cost distances is more appropriate for find density analysis in this region (HERZOG and YÉPEZ 2010). Additionally, the more refined chronological framework developed by Alden Yépez is used in our investigation.

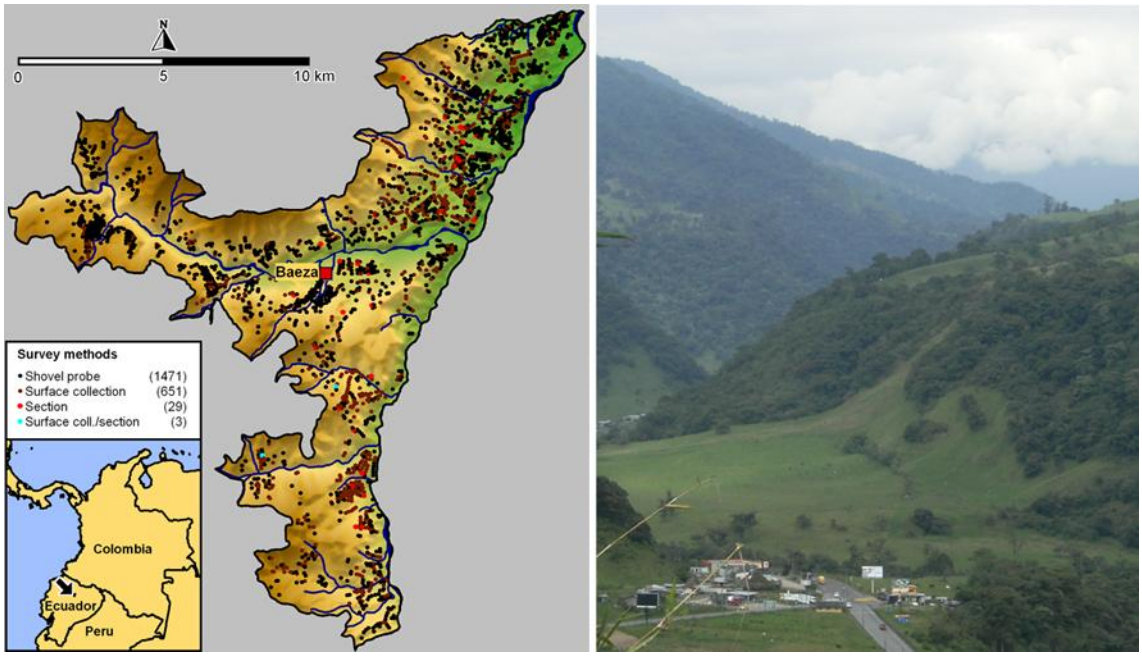

Fig. 1 – Left: The Quijos and Cosanga study area and the centers of the collection units (by I. Herzog, based on ASTER elevation data, which was created by NASA and METI and on the collection unit map published by Cuéllar on the web); Right: Landscape in the study area (by A. Yépez).

Most archaeologists applying find density analysis rely on the assumption that the finds recovered are a random sample of the initial distribution. However, several filtering processes like flooding events or past agrarian use bias the sample. For this reason, a detailed investigation of the filtering processes is required to assess the bias. This is a prerequisite for appropriate steps towards correcting the bias.

Unintentional, informal, and formal filters

ORTON (2000: 1–2) defines three sorts of filters: Unintentional, informal and formal filters. Unintentional filters are processes that take place before the archaeologist arrives on the scene. On arriving on the scene, the archaeologists may choose informal or formal sampling methods. Formal samples are equivalent to random samples, whereas informal samples introduce some bias and therefore lack “the potential for generalization from them”. In the terminology of VAN LEUSEN (2002: 4·1) the term research bias is used instead of informal filter. According to van Leusen, this term includes all forms of bias which occur during the construction of the archaeological record.

Unintentional filters

Unintentional filters reduce the amount of objects created during a certain phase to the fraction that survives and can be recovered today. VAN LEUSEN (2002: 4·1) and BANNING (2002: 72–73) use the term post-depositional bias or factors in this context.

In all inhabited parts of the world, the modern relief is the result of constant changes both by natural forces and many different human activities. Natural forces like erosion or flooding as well as human activities like bulk material extraction or past agrarian use result in unintentional filters. The impact of unintentional filters often changes with time, for example erosion depends on the vegetation which varies due to cultural activities and climatic fluctuations. To identify depositions resulting from natural forces or human activities, geological and soil formation analysis are applied routinely in regional projects in Italy (VAN LEUSEN 2002: 4·10, 8·2). The second-best option is to observe carefully all chance sections due to road cuts and other causes to assess the extent of erosion or deposition (BANNING 2002: 47).

Informal filters

Most informal source filters are visibility or obtrusiveness issues (BANNING 2002: 46–49) which influence the probability of detecting an artifact. Visibility and obtrusiveness depend on the color contrast between the finds and their environment, vegetation cover and weather. Variations in lighting and improved contrast between finds and surrounding material due to recent rain influences the retrieval rates for surface collections (BANNING 2002: 47). VAN LEUSEN (2002: 4·3, 14·2) notes in both the discussion of Italian research traditions and his analysis of Roman remains in Britain, that land use and land cover are important variables which influence the chances of discovery of archaeological remains. He presents a diagram published in 1991 (p. 4·13) which plots vegetation cover versus site density and shows a linear relationship between the two variables. Observer bias, i.e. the differences between walkers picking up artifacts, sometimes plays a role as well (see also BANNING 2002: 214–216, 224–225).

The impact of source filters depends on the location, the period and the material of the artifacts considered. However, statistical analysis requires a minimum amount of data so that it is not always possible to investigate each group of finds separately on a small-scale basis.

Fig. 2 gives an overview over the filtering processes relevant for the finds in the Quijos and Cosanga study area. Unintentional filters are marked by a yellow background, a blue background signifies an informal filtering process. The initial number of finds is reduced by geological filters like land slides, flooding and erosion. Human activities during later occupation relocate and destroy finds as well, for example when constructing new terraces. Natural decay mainly effects badly fired clay, moreover acid soils create damage. When the archaeologist arrived on the scene, she subdivided the study area into an irregular sampling grid, each grid cell covering about 1 hectare. Thereafter, she decided which cells are sampled and on the sampling method applied for each cell. The finds recovered depend for shovel probes on the location within the cell and for surface collections on the vegetation cover.

The next sections describe our attempts to assess and correct the effect of three filters: (i) relocation due to geological events, (ii) the impact of the two main survey methods, and (iii) the influence of vegetation cover on the surface collections.

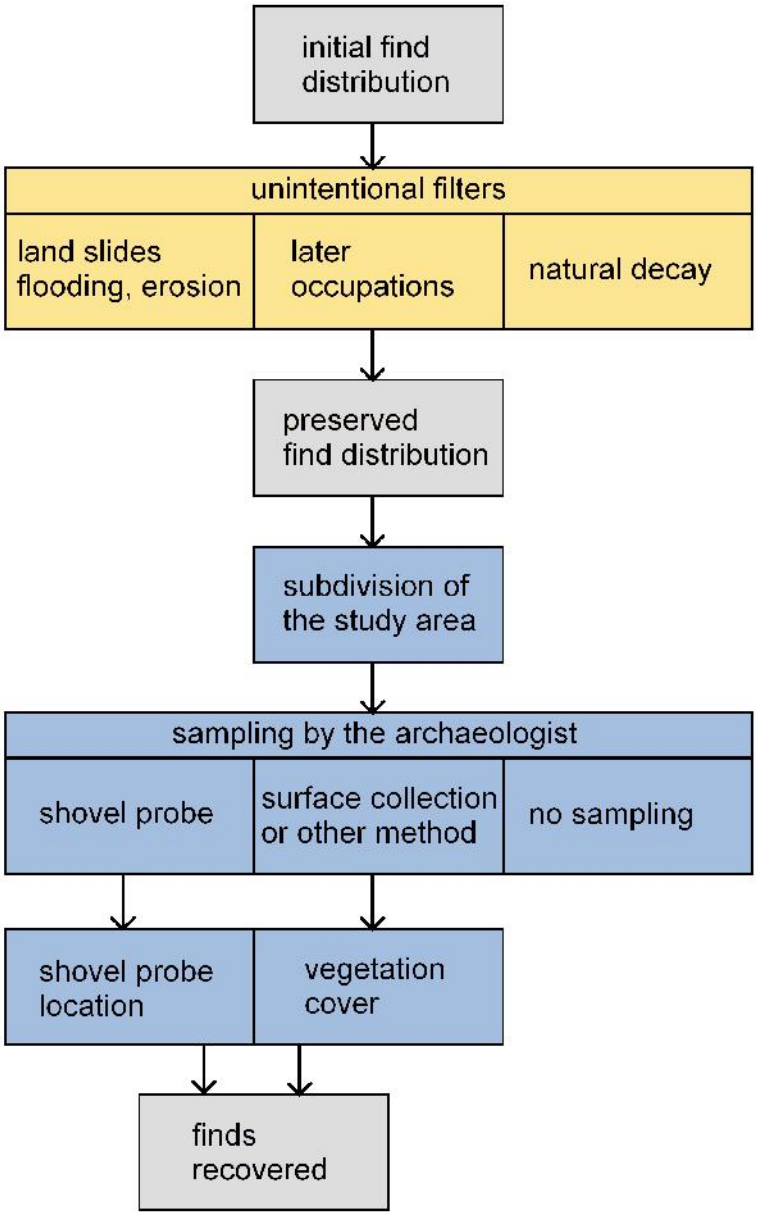

Fig. 2 – Filtering processes of the archaeological finds in the Quijos and Cosanga study area (by I. Herzog).

Geological filters

Geological filters are unintentional in Orton's terminology. According to the CND (1991), Ecuador is exposed continually to earthquakes and other geologic hazards. The report of the Committee focuses on earthquakes which were recorded in March 1987. The two epicenters were located north of the Reventador Volcano and about 50 km northeast of the town Baeza which is in the center of our study area (see Fig. 1). Due to high precipitation rates in the month preceding the earthquakes, surface soils had a high moisture content, so that surface materials and the thick jungle vegetation covering them flowed down the slopes into the rivers. Millions of tons of material were transported into the rivers, with substantial impact on the archaeological landscape: finds were washed away and deposited somewhere else. The CND recorded some debris flows on the highest parts of the Papallacta valley walls a few kilometers east of Baeza and some shallow debris flows in residual soils on the crests of slopes around the town.

The report describes the effect of a single earthquake event, but as mentioned above, Ecuador is located in an active seismic zone so that many earthquakes could have resulted in significant relocation of artifacts. Moreover, the landslide debris can create temporal land-slide dams, which do not only cause upstream flooding by stream impoundment but also major downstream flooding after breaching.

Earthquakes are not the only geological processes that changed the morphology and artifact distribution in the study area. The amount and intensity of rain is high in the study area, (CUÉLLAR 2009: 65–67; annual precipitation in Baeza: 2456 mm) and this induces overflow of rivers and flooding of the areas in the vicinity. Moreover, heavy rains increase the probability of landslides, especially if steep slopes were denuded of vegetation. For example, Cuéllar notes that after two days of heavy rainfall (July 10–11 of 1997), 70 landslides were reported in the transect Baeza-Tena, which covers about 60 km. BUSSMANN et al. (2008) report that in their study area in Ecuador some landslides types were only observed close to a road and that these were due to the road construction. So these landslide types are probably fairly recent phenomena. Nevertheless landslides of these types could have destroyed or covered some of the sites that were present in the Quijos and Cosanga region. Moreover, BUSSMANN et al. (2008) refer to a study in undisturbed forest in Ecuador which recorded visible remains of landslides in 3.7% of the area considered. By analyzing old aerial photographs and ground checks the Bussmann et al. team found that about 8.5% of their study area in southern Ecuador was affected by slide processes during a period of 18 years. Although most landslides recorded by Bussmann et al. were shallow with a depth of less than 1 m, these have serious impact on archaeological surface collections and shovel probes which are limited to a depth of 60 cm.

Poor preservation of artifacts is not the only consequence of landslides and flooding. Moreover, it seems quite likely that landslides and sediments created secondary deposits, and this complicates both stratigraphic and spatial analysis. Thick layers of deposit due to geological processes sometimes cover *in situ* finds, e.g. the CND (1991: 54) recorded young alluvial terraces, 15 to 20 m high, near Baeza.

In conclusion, the climate and slope data as well as the observations of Cuéllar's survey team create the impression that geological filters play an important role.

Attempts to identify relocated sherds

We tried to identify collection units which exhibit evidence of relocation by geological processes or human activities like refilling pits created for bulk material extraction. Several attributes that indicate relocation of sherds were discussed by LÜNING et al. (1971) and THIEME (2008): these include the degree of abrasion, the weight, the maximum length, the size of the sherd and the proportion of thin to medium and thick sherds. According to THIEME (2008: 53–58), several effects on relocated ceramic material are to be expected: The degree of abrasion increases and the average size (i.e. weight, maximum length) of the fragments decreases.

For statistical reasons, we focus our analysis on collection units containing at least ten sherds of the latest phase defined by Yépez (n=441). Data on abrasion and the sherd thickness were recorded for the pottery of our study area. First we analyze these two attributes separately, later the results are combined.

A higher proportion of worn and abraded sherds is often caused by landslides, small-scale erosive processes or fluvial transport. Sherds with fresh breaks are expected in undisturbed contexts. However,

some geological processes do not create any abrasion, and weathering or trampling by cows may cause some abraded sherds which were hardly relocated at all, so that additional relocation indicators are needed to confirm the hypothesis of geological transport. An ordinal scale classification scheme was defined for the sherd edges with four classes: heavily abraded, mixed, somewhat abraded, and sharp edged. A more refined classification could be based on the findings of SCHIFFER and SKIBO (1989), for example to get some clues concerning the abrader and whether wet- or dry-abrasion took place. However, the fairly basic classification used in this study could be applied easily and agrees quite well with the “optical” scheme proposed by THIEME (2008: 53) which consists of five classes.

Of the 441 collection units considered, only 23% contain a proportion of abraded and mixed sherds exceeding 20%. For merely 12 collection units, abraded and mixed sherds account for more than 50% of the sherd total. So in general, abrasion is fairly low compared for example to the layers analyzed by LÜNING et al. (1971), where the proportion of abraded sherds varies between 15.4 and 77.0%. However, the sherds studied by Lüning et al. are considerably older and were recorded in a very different environment.

We defined an abrasion index that is a weighted sum of sherd counts for each class, divided by the total number of sherds in the collection unit. Heavily abraded sherds are assigned a weight of 3, the amount of mixed sherds is multiplied by 2, and the weight for somewhat abraded sherds is 1. In the study area, the correlation between slope and abrasion is low. Moreover, the distribution of the abrasion values cannot be explained by the survey method, the three major vegetation zones or the soil ranking map provided by CUÉLLAR (2009: 87).

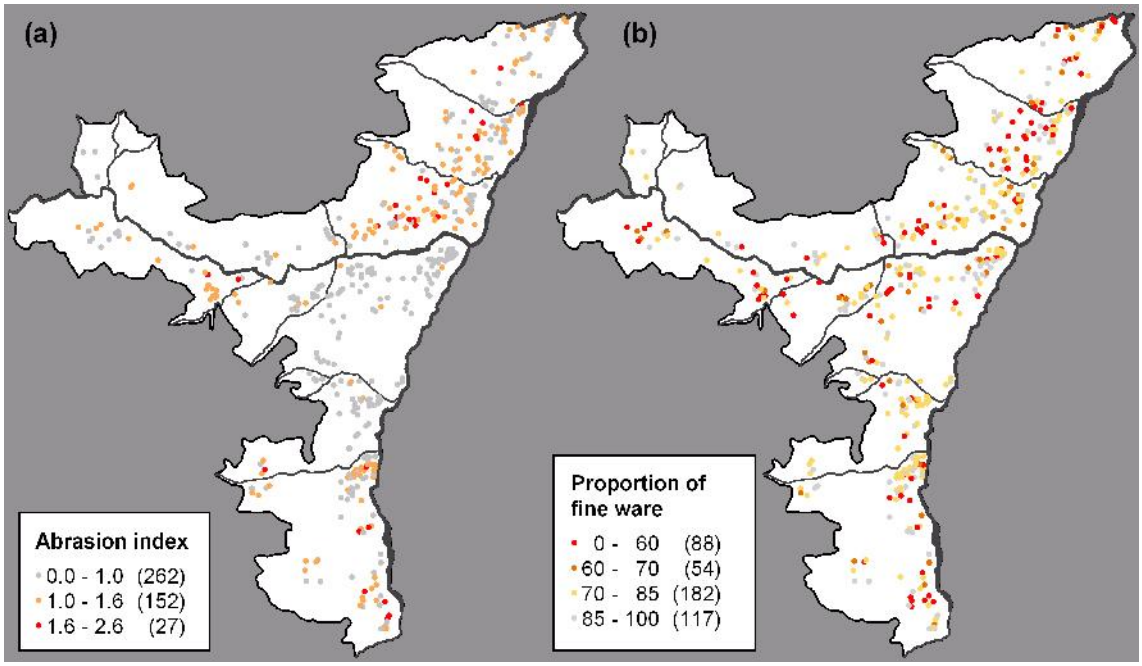

Fig. 3 – Relocation analysis for collection units containing at least ten sherds of the last phase defined by Yépez: (a) Thematic map of abrasion index values (b) Thematic map depicting the proportion of fine ware (by I. Herzog).

The map depicted in Fig. 3a shows abrasion classes that were defined on the basis of the histogram of abrasion index values. Contrary to our expectation, fairly large zones of homogeneous abrasion index values

could be identified: a large area on a plateau north of the river Quijos exhibits high abrasion values whereas the abrasion on the smaller and somewhat higher plateau south of the river Quijos is lower than average. Susceptibility to abrasion depends on the strength and hardness of the sherd (SCHIFFER and SKIBO 1989) as well as the surface convexity (see also: THIEME 2008: 60). The hardness was only recorded for part of the sherds from our study area, instead we analyze the proportion of fine ware. This key figure was not considered by Schiffer and Skibo because briquettes of standard size were used in their study. LÜNING et al. (1971) note that the fragmentation of the pottery depends on sherd thickness. Geological processes often result in additional fragmentation, and for this reason, a higher number of fine ware sherds (with small weights) is expected in contexts resulting from relocation. This is counteracted by the size effect described by ORTON (2000: 62): In surveys, large pieces are discovered more frequently than small ones due to higher visibility.

Three categories were used to classify the sherd thickness: up to 5 mm, 5 to 12 mm, more than 12 mm. Coarse ware with sherd thickness exceeding 12 mm were not recorded for the last phase, so that the proportion of fine to medium ware is analyzed (Fig. 3b). On average, the proportion of fine ware belonging to the last phase is quite high for the subset of collection units considered (72.4%). The correlation between abrasion and the proportion of fine ware is fairly weak (-0.25) and a scatterplot of these two variables confirms that no evident relationship between the two variables exists (Fig. 4).

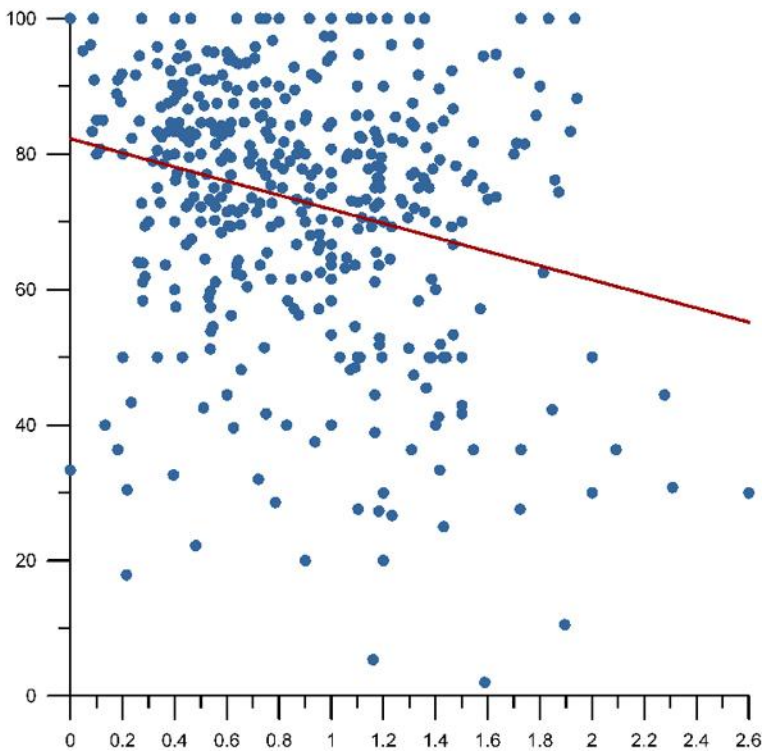

Fig. 4 – Scatterplot of abrasion index (horizontal axis) and the proportion of fine ware (vertical axis) for the phase 4 sherds of 441 collection units. Moreover, the linear function which best fits the points is shown (by I. Herzog).

Without supplemental evidence, it is impossible to decide if abrasion or a high proportion of coarse ware or a combination of both is an indicator of relocation. In some cases the test pits provide additional information: The 2x1 m excavation VQ042 is in the vicinity of high abrasion index collection units on the north plateau.

The nearest collection unit (of the 441 units considered here) contains 11 sherds, 6 of these are heavily abraded. According to CUÉLLAR (2006: 253), a carbon sample from the 20 to 30 cm depth level produced a date of 1613 ± 32 A.D., which is more than 1,000 years later than she expected. This supports the assumption that the material found in this area has been relocated.

The test pits VQ026 to VQ030 are located in an area of high abrasion index collection units, and in this case, cow activities probably caused site destruction (CUÉLLAR 2006: 239). Cattle ranching is prevalent in this region (CUÉLLAR 2009: 61), and so the abrasion and fragmentation may result from cows trampling on the sherds. According to CUÉLLAR (2009: 111), cattle ranchers prefer low altitude areas with gentle relief. This is another possible explanation of the high abrasion rates on the plateau north of the river Quijo and accounts for the lower mean slope of collection units with high abrasion index.

In conclusion, we are not able to identify areas of sherd relocation based on the available survey data, because abrasion and fragmentation may have resulted from cattle ranching. Assessing sherd relocation requires systematic geological observations, moreover, sherd weights should be recorded.

Assessing the effect of different survey techniques and vegetation

As mentioned above, vegetation cover often affects the artifact recovery rate for field walking surveys. So we analyzed the impact of vegetation cover on the survey results in the Quijos and Cosanga study area. This data was readily available: CUÉLLAR (2010) applies an ordinal scale classification scheme to record the vegetation cover (H=high, M=medium, L=low, N=none) for each collection unit published in her sherd table. We found that the number of sherds recorded for surface collections depended on the vegetation density, whereas the distribution of shovel probe sherd counts is independent of the vegetation cover (Fig. 5).

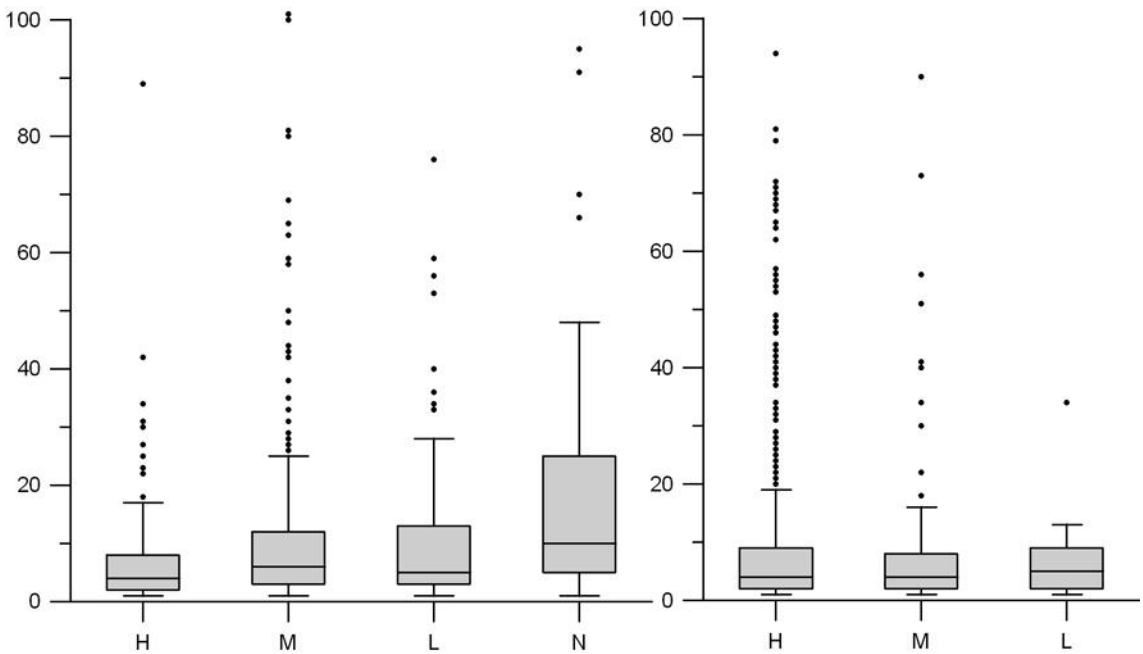

Fig. 5 – Box and whisker plots showing the distribution of the number of sherds in surface collections (left) and shovel probes (right), depending on the vegetation cover: H-high, M-medium, L-low, N-none. Collection units with more than 100 sherds are not shown (by I. Herzog).

Overall vegetation density varies within the study area, and so we entertained some worries that the spatial distribution of the collection units is important as well. For this reason we compared sherd counts of surface collections with those of their nearest shovel probe neighbor (Tab. 1).

Vegetation density	Count	Median Sherd count	Neighbor Median	Average sherd count	Neighbor average	Higher shovel probe count (%)	Correlation	Correct. factor
None	41	10	5	23.65	12.38	31.7	0.1203	0.5
Low	62	6	4	11.73	15.22	30.6	0.0413	0.6
Medium	166	6	4	11.54	11.75	40.4	0.1546	0.8
High	122	4	5	7.19	8.98	45.9	0.1515	1

Tab. 1 – Comparison of 391 surface collections with their nearest shovel probe neighbor with respect to sherd counts.

A total of 391 neighbor pairs with map distance below 150 m was analyzed. Three surface collections with a sherd count exceeding 200 were omitted in the calculation of averages and correlation. The results of Fig. 5 are supported by those shown in Tab. 1: in the absence of vegetation cover, the sherd count of surface collections is nearly twice as high as that of neighboring shovel probes. The sherd counts of surface collections with low or medium vegetation cover present an ambiguous picture: whereas the median of the collection unit is higher, the average sherd counts are similar or lower than that of their shovel probe neighbors. High vegetation cover results in somewhat lower median and average sherd counts of the surface collection. We also calculated the percentage of pairs where the number of sherds recorded for the shovel probe exceeds those of the surface collection neighbor. This value guided us in choosing the correction factor for the sherd counts of surface collections: the correction factor ensures for each vegetation cover class that the surface collection sherd counts exceed those of the neighboring shovel probe in roughly half of the cases considered. According to VAN LEUSEN (2002: 4·14–4·17), the simplest method for correcting bias is to multiply the counts or weights of retrieved material categories by the inverse of the relevant bias percentage. We apply this approach to compensate for the bias introduced by vegetation cover. However, the low correlation values between the sherd counts of surface collections and that of their nearest shovel probe is not quite what we expected (Tab. 1).

We hoped that the sherd count variability is lower when merging collection units in areas with fairly uniform geographical conditions. A successful correction of the sherd counts recorded for the survey collections should result in comparable sherd averages for both survey methods within such a larger scale area. We defined as many test areas as possible with reasonable uniform structure and a mixed distribution of both survey types (Fig. 6). The test areas were initially delimited on the basis of an accessibility map and after that, they were clipped to ensure homogenous soil attributes within each test area. The sizes of these test areas vary from 30 to 192 hectare. Each test area includes at least 25 collection units and five instances or more of each survey type. Five collection units with a corrected total of more than 100 sherds were omitted in the calculation of the averages.

	Shovel probes		Surface collections		
Test area	Count	Sherd average	Count	Sherd average	Corrected average
1	18	4.17	7	3.29	2.77
2	26	12.12	8	46.00	29.10
3	32	12.69	47	10.85	8.61
4	16	12.31	12	16.50	14.02
5	14	14.21	16	11.31	9.86
6	42	10.07	10	3.80	2.72
7	24	6.38	10	6.10	3.98
8	53	7.26	7	5.43	5.06
9	14	12.86	12	7.08	6.33
10	26	18.85	10	55.20	29.15
11	7	12.00	30	6.43	3.86
12	13	6.85	11	14.82	12.07
13	13	7.08	12	4.17	4.03
14	13	4.00	16	5.56	4.56
15	20	10.35	5	9.60	9.24

Tab. 2 – For each test area and survey type the number of collection units and the sherd count averages are listed. For the surface collections, the corrected averages are shown as well.

In general, for surface collections with a sherd count average below 10, the difference between the averages of surface collection and shovel probe increases after the correction whereas for larger averages, the corrected averages come closer to the shovel probe averages (Tab. 2). However, for areas with rich surface collections on average, a correction factor resulting in an even lower average seems more appropriate. In conclusion, on the test area scale, the average sherd count of surface collections is not an adequate estimate for the ceramic artifacts recorded in shovel probes. Correcting the sherd counts of surface collections as suggested above, decreases the difference between the two averages mainly for test areas with rich surface collections.

Moreover, we tried to check if different survey methods lead to different proportions of finds with respect to our chronological classification. It is likely that the percentage of early sherds is higher in shovel probes than in surface collections, because according to the laws of superposition, early sherds are often covered by later layers. The spatial distribution of the collection units should be taken into account for this test, and for this reason we once again used the test areas defined in Fig. 6.

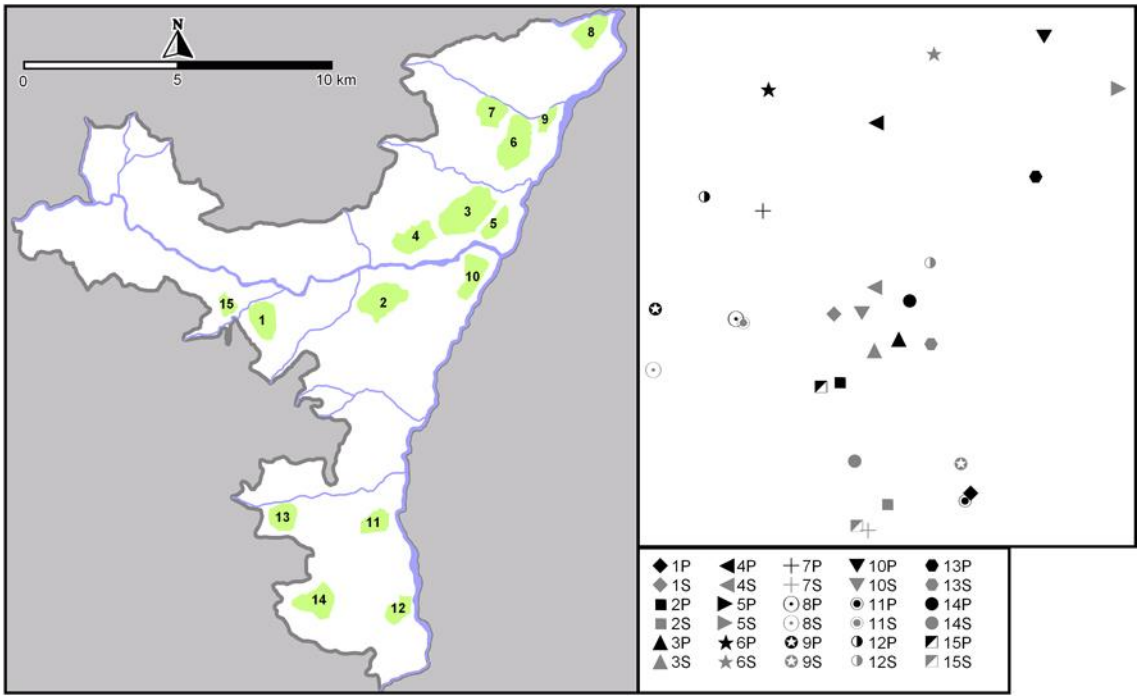

Fig. 6 – Map of 15 test areas (left) and correspondence analysis plot of the first two axes for the chronological profiles within these test areas (right). The legend entries refer to the test area number given in the map and the survey method: P=shovel probe, S=surface collection (by I. Herzog).

To calculate the chronological profile of a test area and a given survey method, the corresponding sherd counts for each phase were accumulated. For surface collections, phase 1 sherds were underrepresented in 12 of the 15 test areas, whereas the proportion of phase 4 sherds is higher than that of the shovel probes in eleven test areas. In nine cases, the proportion of phase 2 and phase 3 sherds is lower for surface collections than for shovel probes. A chi-square test seemed to be appropriate (e.g. BAXTER 2003: 128–131) to check if the sherd counts of both survey methods show similar chronological proportions. The test is somewhat problematic because it requires that 80% of the expected values are at least 5, which is violated within several test areas due to the small amount of sherds recovered from the first three phases. Even with Yate's correction, some initial tests for several test areas rejected the hypothesis that the frequency distributions of the chronological profiles from the two survey methods considered belong to the same distribution at a high level of significance. Instead of discussing individual test results, we decided on performing a correspondence analysis (e.g. BAXTER 2003: 136–139), which allows depicting the chi-square distances within a set of assemblages (Fig. 6). The plot which accounts for 86.7% of the variance creates the impression that no straightforward relationship is detectable between the chronological profiles of shovel probes and surface collections within the same test area.

In conclusion, our analysis of the relationship between sherd counts of shovel probes and nearby surface collections did not produce a simple correction function which is applicable throughout the study area.

Assessing the variability of nearby shovel probes and test pits

According to DRENNAN and BOADA RIVA (2006: 59), the artifact densities of shovel probes within each survey lot of up to 1 ha varied substantially in the Valle de la Plata study area in Colombia. They come to the conclusion that the average artifact density of a survey lot is not well represented by a single shovel probe. This issue is not discussed in Cuéllar's studies. For this reason we analyzed 1,150 shovel probe pairs with neighbor distance below 125 m. A very low correlation was found in this case as well (.0837). Restricting the neighbor distance values to less than 75 m resulted also in a low correlation (.0404). Measuring the sherd counts on a logarithmic scale so that less weight is attributed to rich samples likewise had a low correlation (.1501). So generally speaking, the analysis shows a high spatial variability of the sherd counts recorded for the collection units. The sherd count of a collection unit is not an adequate estimate for the ceramic artifacts collected for a neighboring sample, even if the sample distance is below 75 m.

Although neighboring samples show differing sherd counts, the chronological profiles in terms of proportions should still be similar, when assuming that these are samples drawn from the same population. This assumption can be tested by comparing the inventory of adjacent test pits. In fact, the test pits form 16 spatial clusters, each comprising two to four locations. Only one test pit could not be assigned to a cluster. The average distance between a test pit and its cluster center is 34.36 m. In the chapter on agricultural production and food consumption CUÉLLAR (2009: 121–155) introduces place names for some of these clusters, the other clusters are named G1 to G6.

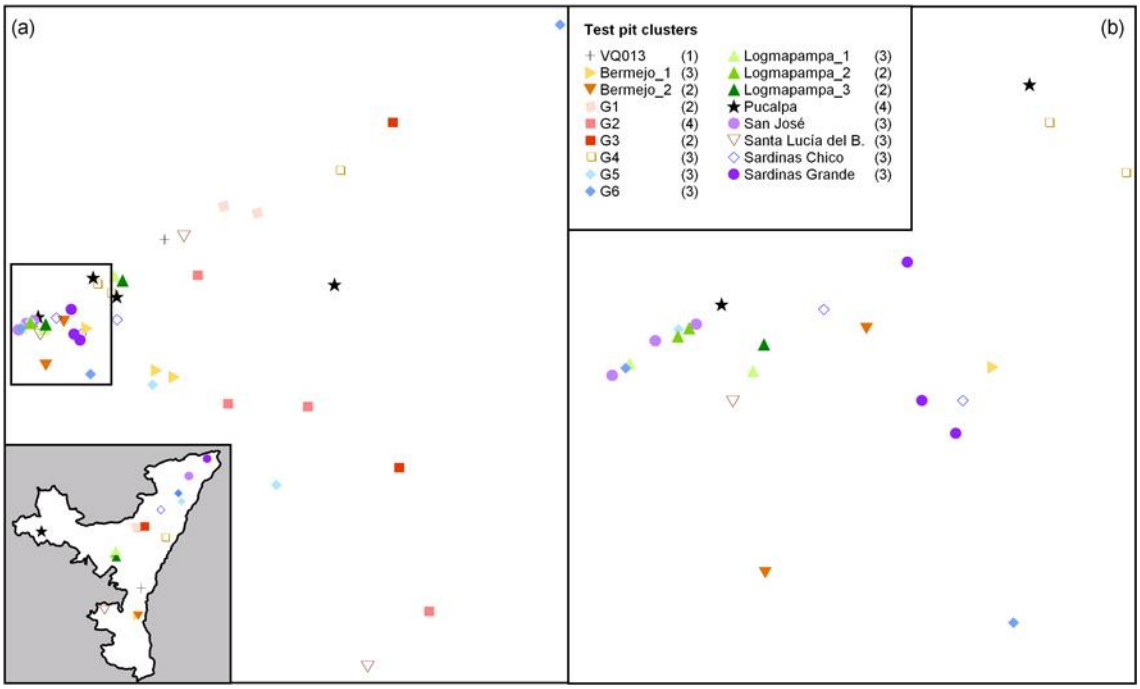

Fig. 7 – Correspondence analysis of the test pit contents up to a depth of 60 cm. The test pit groups are depicted on the inset map, the frame in diagram (a) is enlarged in diagram (b) (by I. Herzog).

The test pits were excavated in layers of 10 cm depth. Our analysis includes only the first six layers, so that the sherds recovered from these layers are comparable to the shovel probes. On average, 152.3 sherds were recorded per test pit up to a depth of 60 cm. However, the sherd counts referring to the first three

phases are fairly low, with median values of 2, 3.5 and 6 respectively. Fig. 7 shows the result of the correspondence analysis (CA) performed on the chronological profiles resulting from merging the first six layers of each test pit. The first two axes shown in the plot account for 78.2% of the variation.

In the CA result, the spatial clustering is only reflected for some test pit groups. Omitting the four test pits excluded by CUÉLLAR (2009: 121) because they “revealed obviously disturbed deposits or contained early materials to a worrisome extent”, hardly changes the outcome at all. A similar picture results when Cuéllar's chronological scheme is applied which consists of three periods only. This demonstrates that in many instances the chronological profile of a collection unit based on sherd counts is not an adequate estimator for the sherd proportions found in a nearby location.

The previous paragraphs show that in the study area, at short distances the archaeological record changes significantly when focusing on sherd counts. In fact, many archaeologists have studied sherd counts and found that they do not represent the number of vessels deposited initially, therefore alternative estimators have been proposed. Both ORTON (2000: 51–53, 57) and BAXTER (2003: 216) favor sherd weight as an unbiased estimator for the initial compositions of the pottery types considered. Unfortunately, the sherd weights are not available for the data set considered here. An alternative and even more statistical sound approach is the estimated vessel-equivalence statistic (in short: eve statistic) proposed by Orton.

Results of the bias analysis and suggestions for improvements

Relocation processes due to natural forces play an important role in the study area, though it was not possible to identify areas with secondary deposits reliably. Additional bias is introduced by mixing two survey methods. For surface collections, the number of sherds recorded seems to depend on the vegetation cover and on other factors. Alternatively, percentages of sherd types instead of sherd counts could be analyzed (e.g. CUÉLLAR 2009: Tab. 2.1, p. 28). However, the proportions with respect to the chronological classification of the sherds vary for both survey types within each test area: in most, but not all test areas, early sherds are underrepresented in surface collections. The spatial variability of the samples raises the question whether a higher sampling rate could change the picture significantly. Sherd counts are probably not adequate, alternative estimators for the number of ceramic objects should be tested.

Our analysis demonstrates that the survey data are not a random sample of the pottery present during the phases considered. Unfortunately, we were not able to correct the combined bias introduced by the effects listed above. In our view, any find density or settlement pattern analysis based on the uncorrected sherd quantities means skating on thin ice.

Possible improvements of the survey methodology include recording of the sherd weights. This might help to identify areas with relocated finds and provides an alternative approach for comparing neighboring collection units. Applying shovel probes only, but with a low distance to the nearest neighbor, most likely creates more reliable samples.

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MUSINT: a virtual habitat for relocated archaeological artifacts

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Abstract: The purpose of this contribution is to present an educational and interactive tool to be accessed on-line to share knowledge about Aegean archaeological collections held by various museums in Tuscany, Italy, and reconnect them to the geographical sites they come from, recovering also the historical, cultural and technical information to understand better the importance of the artifacts which suffer of limited visibility where they are now kept. The paper is tailored to show how the described structure and exploration modalities of MUSINT’s virtual museum meet these expectations, addressing one of the subject fields offered by the displayed contents: the Cretan collection in Florence, and particularly, within the collection, they clay finds from the Messara region, where the excavations of the renowned sites of Haghia Triada and Phaistos were carried out by the Italian Mission in Crete from the beginning of the 20th century. The documentation made available to the visitor in the system includes texts, adapted also for younger users, old and new photos, maps and plans of the sites, 3D models of the artifacts based on their metric survey, hypothetical reconstructions, drawings and cartoons, providing an incisive integration which recreates the historical context of each find and offers in-depth examination on demand.

Keywords: archaeological collections, Crete, virtual museum, 3D models.

Introduction

This paper illustrates just a section of the contents of a broader project, titled MUSINT, currently dedicated to *The virtual museum of the Aegean and Cypriot collections in Tuscany*, soon available on the Web[9], and synthesizes its implementation. The project aims to connect regional archaeological collections and share knowledge about medium and small size artifacts stored in far apart museums and not usually accessible to visitors, in spite of their distinguished value in terms of quality and variety of the repertoire. But this is only the primary purpose of MUSINT. It seems, in fact, particularly relevant to create also a further connection between the objects exhibited today in a museum and the place where they were originally located – obviously, in case provenance is known – guiding MUSINT’s visitor along an itinerary to discover the object’s historical and geographical initial context, an itinerary which starts from the last relocation, unrelated to the object’s nature. This is precisely the subject matter of our contribution, which aims to explicate one of the possible applications of MUSINT.

[9] The virtual museum of the MUSINT project, sponsored by the Region of Tuscany, will be soon available on-line, within a dedicated web portal. A volume (JASINK et al. 2011) has been published to support the project: it’s focused not only on its description and realization, but also on further conceivable implementations suggested by the project.

The specific field of study we have presented during this Conference is limited to the Cretan collection in Florence, and, within the collection, to clay finds from the Messara region. Consequently, on one side we illustrate some aspects of the southern area of Crete where two of the most important sites of the Minoan civilization flourished: Haghia Triada, with its *villa* dominating over the lower town and an annexed necropolis extending at its feet, and Phaistos with its palace at the center. On the other side, we take into consideration the Archaeological National Museum of Florence, which holds some of the artifacts found in the two mentioned sites, due to the fact that the excavations of Haghia Triada and Phaistos were carried out by the Italian Mission in Crete, started at the beginning of the 20th century, and a number of such objects were given as a token gift to the Florentine Museum.

Fig. 1 – The *villa* of Haghia Triada after the excavations (Photographic material from SAIA – Italian Archaeological School in Athens, kindly offered by the Director, Prof. E. Greco).

The sites

Our contribution is focused on a limited time span of the two archaeological sites of Haghia Triada and Phaistos. As for the first, we will be considering the 16th and the first half of the 15th centuries BC, the phase belonging to the Minoan Neopalatial Age when the Minoan civilization reached its greatest power – in the political field as well as in the economic and artistic ones. The big *villa* was built on the higher slopes of the hill (Fig. 1)[10]. Some rooms were used as administrative offices and deposits: around 1250 clay objects have been found, and these can be divided in four main typologies: tablets, roundels, *noduli* (sort of tokens with no direct contact with the objects they are related to) and nodules (attached to items of interest either directly or

[10] This and other following images go back to the first excavations of the site by F. Halbherr, reflecting the situation when the objects of our interest were found and sent to the Museum of Florence.

through a string) (Fig. 2). Other places which must have had the same function were found also downtown, in particular in the so-called *Casa del Lebete* (Fig. 3).

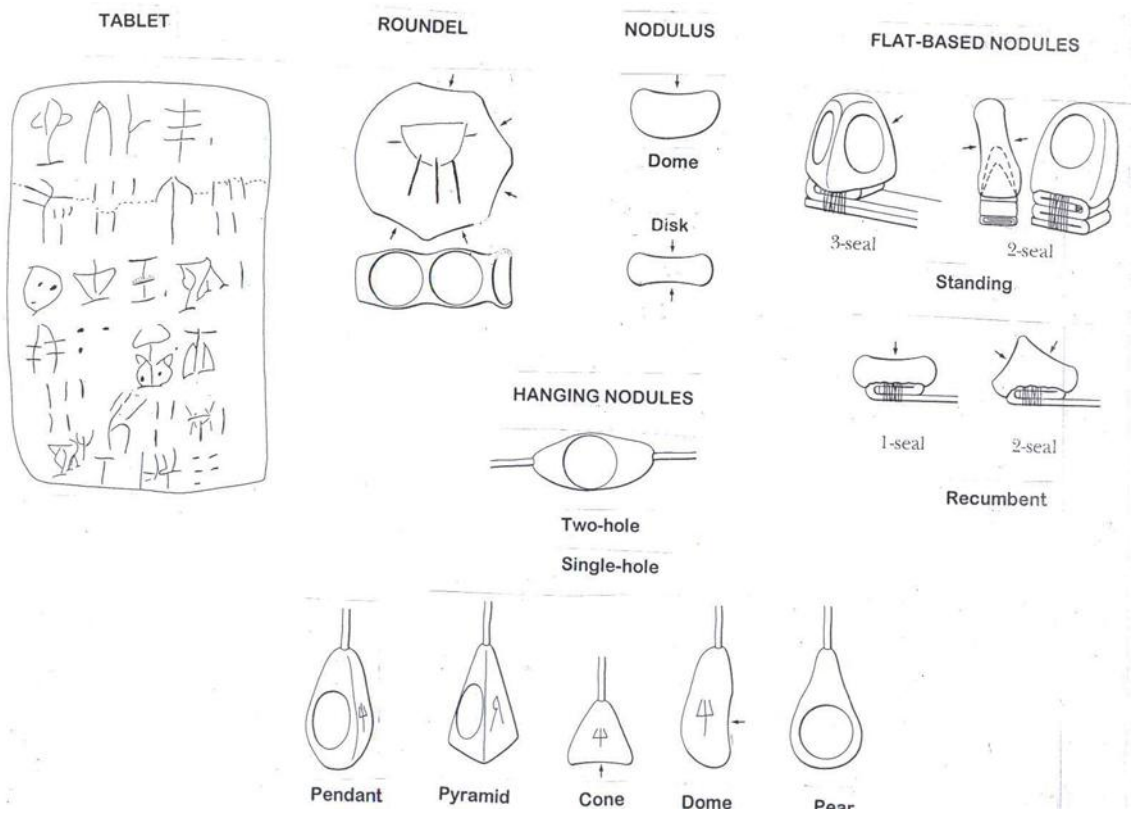


Fig. 2 – The various typologies of administrative documents from Haghia Triada (elaboration from HALLAGER 1996: 23, 32).

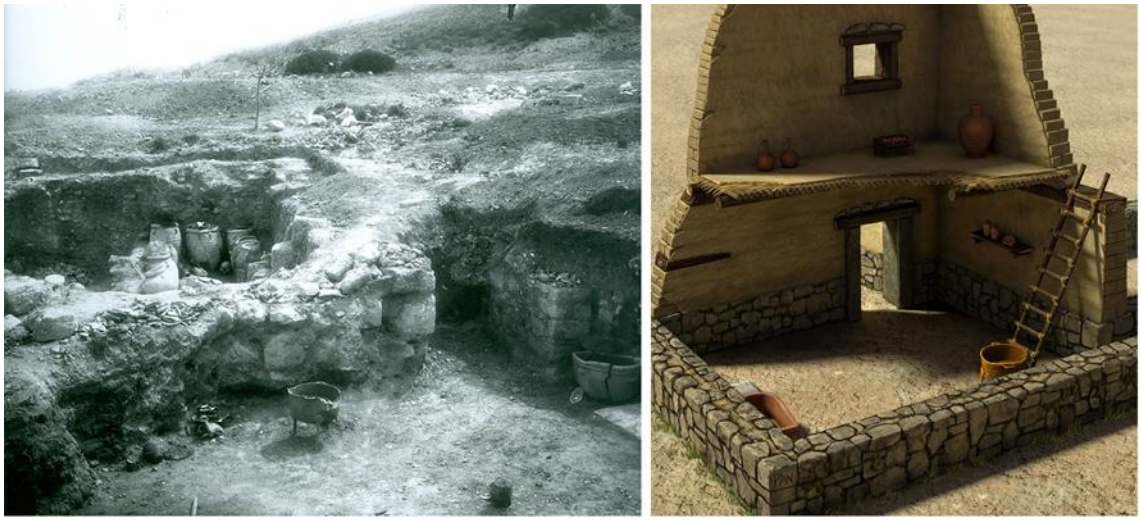


Fig. 3 – *Casa del Lebete*: on the left, photo following the excavation (Photographic material from SAIA – Italian Archaeological School in Athens, kindly offered by the Director, Prof. E. Greco), and on the right, hypothetical reconstruction by P. Kruklidis.

Concerning the palace of Phaistos (Fig. 4), located on another hill overlooking the Messara plain, we will concentrate on a previous phase, characterizing the Protopalatial Age, around the 19th and 18th centuries BC, when various palaces in the island (the best known are those of Knossos, Phaistos and Mallia), ruled

over different areas of Crete. As for the palace of Phaistos we don't have a complete knowledge of the complex for this period, since a second palace was rebuilt over the first – at the same time when also the *villa* of Haghia Triada flourished –, but we had the possibility to recover some parts of the older palace because it was bigger than the new one and because they were separated by a concrete filling. In the open square which extended in front of the western facade of the second palace, the floor just consisted of this stratum of concrete (Fig. 5), which was cut by the excavators and revealed the remains of parts of the first palace with the objects therein, and many other fragments put under the concrete to fill the space between the old and the new palace. During the Protopalatial Age, the period of our interest, the best attested ware is the so-called *Kamares ware*, which derives its name from the first findings in the Kamares cave, on the slopes of Ida mountain, in front of Phaistos.

Fig. 4 – A general view of the ruins of Phaistos palace in a photo following the first excavations and before the removal of the western "filling" (LEVI 1976: Tav. 3/b).

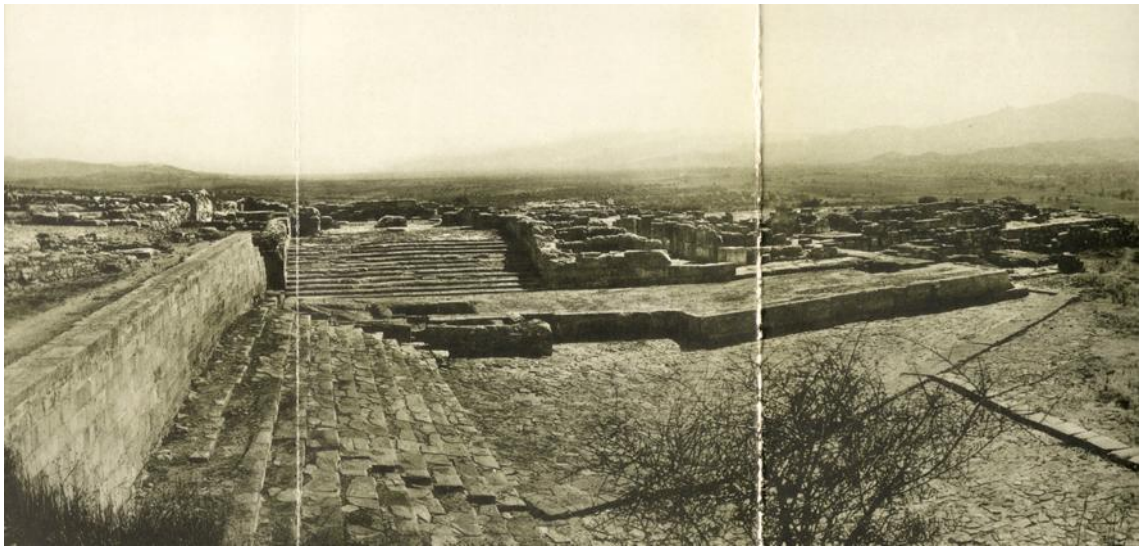


Fig. 5 – View of the ruins of Phaistos from the western facade, with the stratum of concrete covering the First Palace (PERNIER 1935: Tav. IX).

Why are we choosing these particular periods for our paper? Because many examples both of the administrative documents at Haghia Triada and of the *Kamares ware* are actually in the Florentine Museum

and their analysis allows, as we underlined at the beginning of this work, to develop an interactive museum or, better, an itinerary starting from Messara and arriving to Florence.

The excavations of both sites in Messara started at the beginning of the 20th century, undertaken by the Italian Archaeological Mission in Crete, under the direction of Federico Halbherr. The two main Italian figures who promoted the activation of this Mission where Luigi Pigorini and Domenico Comparetti, the first the founder of the Museo Preistorico Etnografico in Rome and the second the founder of the Regio Museo Archeologico of Florence – the present National Archaeological Museum –, which for a long time was directed by Adriano Milani. Their interest to start the archaeological Mission in Crete gave the opportunity to both museums to receive finds directly from the excavators and to create an uninterrupted channel of contacts with the Greek authorities and with Greek art dealers. From here on we will focus on those few objects of which we know the precise original location inside both sites and which were sent to Florence.

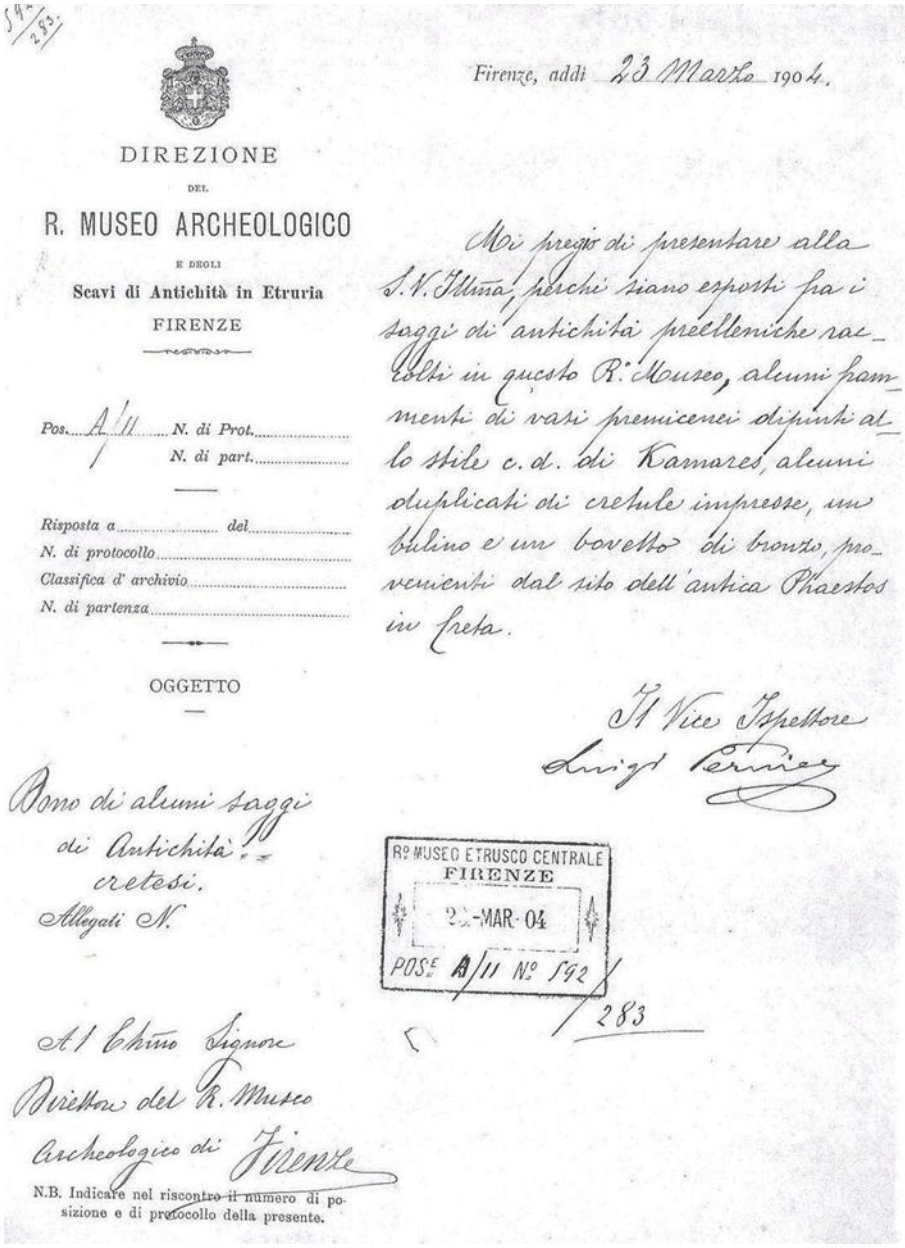
Fig. 6 – Three of the nine nodules of the National Archaeological Museum in Florence from Haghia Triada: in the first row, faces with seal; in the second, faces with incised symbols; and in the third, imprints.

The materials

At Haghia Triada there was, as we stressed above, an extensive administrative activity. In the Florentine Museum only 9 sealings arrived from Haghia Triada – 8 hanging nodules with one hole and 1 with two holes (Fig. 6)[11] –, officially sent with other objects by Luigi Pernier, field director for the Italian Mission, to Milani, as

[11] For a description of the single objects see CR. 225–233 in JASINK and BOMBARDIERI 2009.

we read in a letter of 1904 (Fig. 7). In the other Italian museum, the National Prehistoric Ethnographic Museum “L. Pigorini” in Rome, besides 25 nodules and 5 *noduli* (DEL FREO 2002–2003) also 3 clay tablets are exhibited coming from the same areas as the other small administrative documents (MANGANI 2004: 296). Obviously the greatest number of these objects are located in the Heraklion Museum in Crete. We don’t know where the “scribes” of Haghia Triada actually carried out their activity, but we suppose that it was very close to the rooms where the objects have been found, at least in the same quarters of the villa, where stock rooms, deposits and archives where likely connected.


DIREZIONE
DEL
R. MUSEO ARCHEOLOGICO
E DEGLI
Scavi di Antichità in Etruria
FIRENZE

Pos. A/11 N. di Prot.
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Risposta a del
N. di protocollo
Classifica d' archivio
N. di partenza

OGGETTO

Dono di alcuni saggi di Antichità cretesi.
Allegati N.

Firenze, addì 23 Marzo 1904.

Mi pregio di presentare alla S. V. Illma, perchè siano esposti fra i saggi di antichità preellenische raccolti in questo R. Museo, alcuni frammenti di vasi premicenei dipinti allo stile c. d. di Kamares, alcuni duplicati di cretule impresse, un bulino e un bovetto di bronzo, provenienti dal sito dell'antica Phaestos in Creta.

Il Vice Ispettore
Luigi Pernier

R° MUSEO ETRUSCO CENTRALE
FIRENZE
23-MAR-04
POS.E A/11 N° 592

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Al Chmo Signore
Direttore del R. Museo
Archeologico di Firenze

N.B. Indicare nel riscontro il numero di posizione e di protocollo della presente.

Fig. 7 – Letter written by L. Pernier to A. Milani in 1904 to accompany the finds sent to the Archaeological Museum in Florence (Archivio Storico della Soprintendenza per i Beni Archeologici, Firenze).

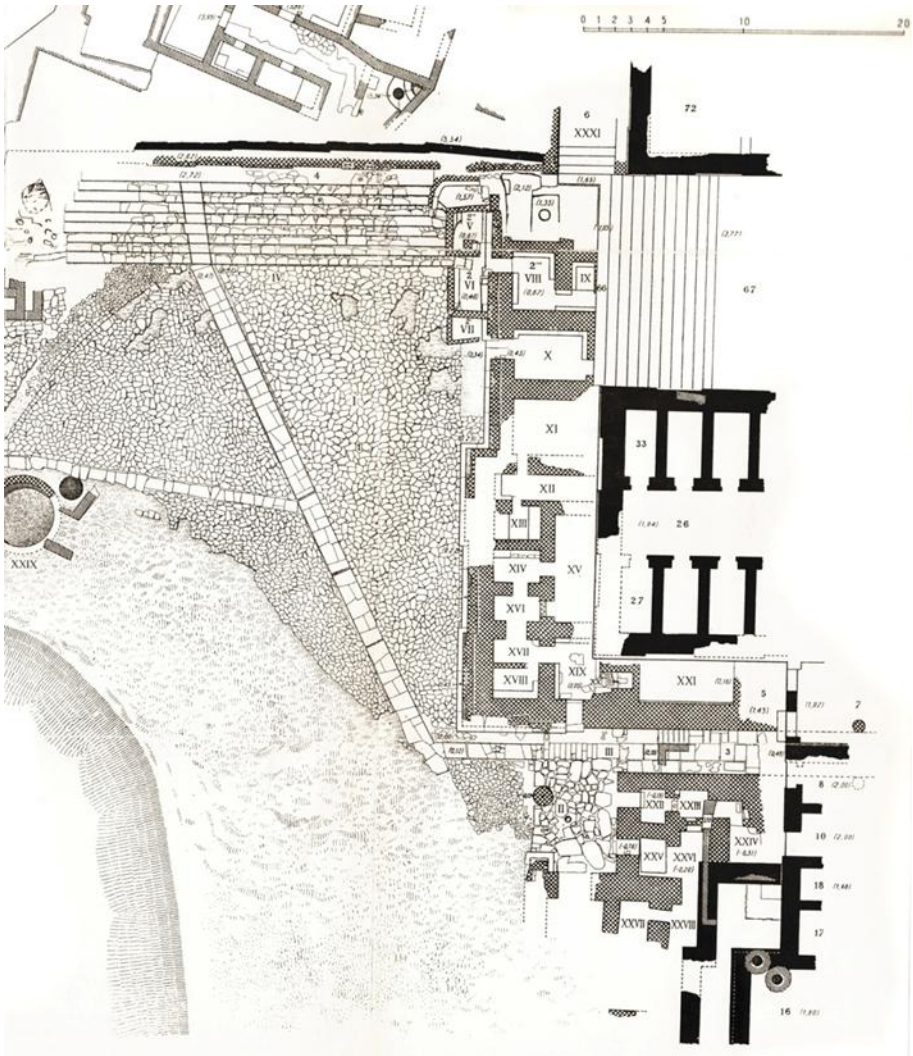


Fig. 8 – Map of the western side of the First Palace of Phaistos (PERNIER 1935: Tav. V).

Concerning the former palace of Phaistos, we have in Florence many exemplars of *Kamares ware*, but only 4 of them have been found in specific locations (Fig. 8). The first two pieces are both *one-handled truncated conical cups*, one (Fig. 9) found generically during the removal of the western “filling” of the first Palace, and the other (Fig. 10) found in the “sacrifical pit” at the basis of the staircase XXXI, where a large quantity of Kamares ware and stone vases, animals’ burned bones, cinders and coal were piled up, all objects meaning the sacral character of the pit, as it may be supposed also from its contiguity to a series of *sacella*. The third object in Florence is a small spouted miniaturistic jug with a crushed globular body (Fig. 11), from Room XVII which is considered one of the small storerooms (X–XVIII) in the western area at the south of the *sacella*. The last piece is a wide-mouthed miniaturistic jar (Fig. 12) from Room XXVII. This room and Room XXVIII are the southern rooms excavated in this section of the palace and their southern wall doesn’t exist anymore.

Fig. 9 – Cup from the western “filling” of the First Palace of Phaistos, CR. 135 (JASINK and BOMBARDIERI 2009).

Fig. 10 – Cup from the “sacrifical pit” of the First Palace of Phaistos, CR. 137 (JASINK and BOMBARDIERI 2009). On the upper right, water-color painting of the same cup by Emilio Stefani, the exceptional drawer of the Italian mission (PERNIER 1935: Tav. XX).

Fig. 11 – Small jug from Room XVII of the First Palace of Phaistos, CR. 146 (JASINK and BOMBARDIERI 2009).

Fig. 12 – Small jar from Room XXVII of the First Palace of Phaistos, CR. 147 (JASINK and BOMBARDIERI 2009).

The virtual itinerary

Among the Aegean artifacts displayed in MUSINT's on-line virtual museum it's possible to examine a selection of the Cretan collections, including also the objects which have been described above *in situ*, that is in their primary location: 4 vases from Phaistos and 9 nodules from Haghia Triada, held by the National Museum in Florence.

The system offers different paths for the visitor to follow: he can start choosing the location of interest from a map of the Aegean Sea and surrounding regions (Greece, Crete, Cycladic islands, Rhodes and Cyprus), and then consult a time-line chart which will give him various kind of historical, geographical and cultural information on the finds produced in a single time span (Fig. 13). Or he can read all data made available and explore images (or 3D models) of the artifacts through their single descriptive sheets (Fig. 14) selecting one of the proposed typologies of manufactured production, symbolized by icons, for a specific region.

Fig. 13 – Selecting region Crete in MUSINT's virtual museum of the Aegean and Cypriot collections in Tuscany.

Fig. 14 – Example of the descriptive sheet of one of the finds which can be digitally explored in 3D.

Another approach to the exploitation of the available documentation is to access galleries of images regarding a distinct location where the finds come from: photos, plans of excavated sites, drawings and renderings. It seemed very useful to present the artifacts in our digital interactive museum combining pictures of the present condition and of the early 20th century, when they were found, with hypothetical reconstructions of the sites, realized through computer graphics, as in (Fig. 15)[12].

Fig. 15 – The *villa* of Haghia Triada in a hypothetical reconstruction by P. Kruklidis.

Younger visitors are invited by the cartoon of a mythological character, as Minotaur in the specific case of Crete, to discover – through his story-telling and suggestions – the contents of the virtual museum in a guided and adapted itinerary.

Three-dimensional models

On a total of 100 finds available in the current digital interactive repository, a selection of about 40 pieces has been digitized in three dimensions for real-time visualization of their present condition, and a few of these are Cretan.

The resulting 3D models allow to explore the objects they represent very faithfully from other viewpoints than the ones permitted by normal and direct non-contact inspection, not to mention the very limited ones offered by photos. And the reviewing at close range allowed by the system’s zooming options on the virtual replica may be at a scale larger than real.

The digital copies which can be seen on the on-line application (e.g., see Fig. 16) are based on sets of thousands (or even millions) of points accurately measured on the external surfaces of the objects and on the visible parts of the internal ones. This means that the final 3D models preserve high fidelity to the real objects. Most of the selected artifacts have been surveyed with a triangulation-based laser scanner[13]; a few

[12] On particular techniques for a multimedial reconstruction of archaeological remains in geographical areas see KRUKLIDIS 2011.

[13] NextEngine: <http://www.nextengine.com> (accessed 28/02/2012).

have been digitized with photogrammetric techniques[14], based on the use of a calibrated digital reflex camera, a slide bar and a proprietary algorithm for multifocal image analysis and generation of high-resolution point-clouds where every point is identified by 6 values, the x y z space coordinates and the RGB color ones.

Fig. 16 – Three-dimensional models of a cup, CR. 133, and of a seal, CR. 211 (the two images are not scaled). The first one has been digitized by means of a triangulation-based laser scanner, the second one with micro-photogrammetric techniques.

Fig. 17 – Laser scanning a stirrup jar from Rhodes at the National Archaeological Museum in Florence.

[14] ZScan by Menci Software: <http://www.menci.com/zscan/index.php?lang=en_EN> (accessed 28/02/2012). For the description of the photogrammetric techniques employed for MUSINT refer to MENCI et al. 2011.

The desktop laser scanner we used acquires shape data of the scanned object (recorded in the instrument’s space coordinate system), sweeping its 4 laser stripes across the encountered surfaces (Fig. 17), and also correlated photos through its built-in camera for color textural information of the same parts. The acquisition process is quite short and basically automatic once the setting of parameters (e.g., distance and resolution) and the choice of the right supports and arrangement of the artifact – for every needed view – are done. The object may be resting or standing on a rotating base which turns on predefined steps, connected to the scanner.

The challenge is to cover all surfaces, regarding safety conditions for the artifact and the ideal distance between object and scanner at every different angle, in order to have good quality in the resulting data; but at the same time the goal is to achieve all this with the minimum number of scans, which in a second moment will have to be filtered and combined. At the end of this first phase, several point-clouds of very dense geometric samples on the visible surfaces of the object are created and can be visualized with their related texture.

The collected information is then processed to obtain the digital three-dimensional model, aligning separate scans and then all sequences together, cutting out low quality and redundant data, and fusing all patches in one polygonal mesh. At this point a few small areas may be still missing especially in undercut and narrow hollowed regions (Fig. 18).

Fig. 18 – Model of cup CR. 133 after volumetric fusion, to be used for specific studies on the artifact’s shape and dimensions.

Fig. 19 – The final model of cup CR. 133, to be used for the virtual exhibition: solid view with triangles' edges on the upper right and below (detail), and textured view on the upper left.

For each object we have made available a digital copy for the virtual exhibition and one for scientific examination on request. The two different uses have demanded the definition of separate processing procedures, on the basis of the same acquired data[15]. On one side, we have pushed the elaboration process far beyond mesh fusion, completing an accurate photo-realistic reconstruction of the whole object (Fig. 19), conveniently simplified in order to be easily viewed on the Web application, and edited in its textural appearance to mitigate color and tone variations derived from the source photos and remove reflections given by shiny surfaces. On the other, after merging the selected grid surfaces, we have obtained a highly detailed and precise virtual replica of what of the object the device could capture: this 3D model may be measured without any direct contact on the artifact, guaranteeing sub-millimetric accuracy, and also be used

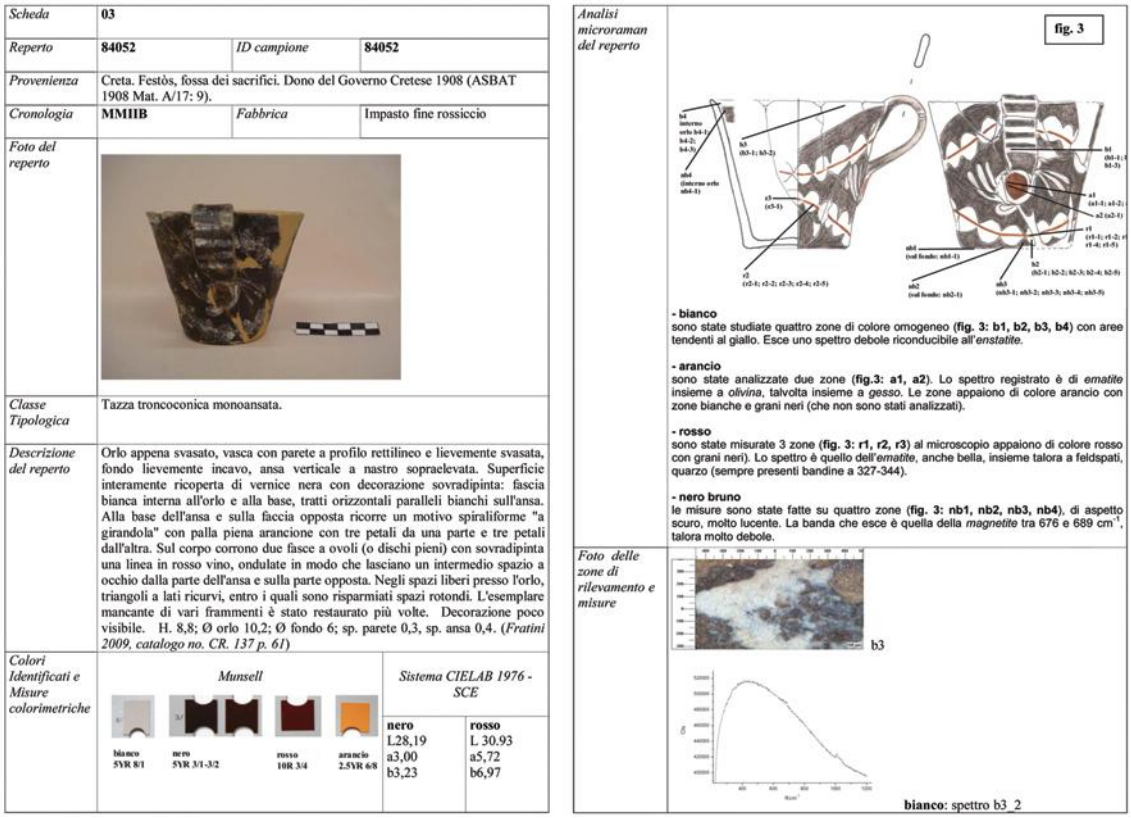
[15] For a detailed review of all acquisition and processing stages and of problematic issues see TUCCI, CINI, NOBILE 2012.

to extract sections, in order to show e.g. the ceramic vessel’s morphological irregularities and thickness where the internal parts have been acquired by the instrument.

As a consequence of our testing different procedures on different shapes and materials, we optimized a methodology and prepared a clear exposition of technical guidelines to be followed easily also by non-specialized digital information providers and in other similar Cultural Heritage applications[16].

Archaeometric analyses

An archaeometric study of the *Kamares* wares in Florence has been carried out, and particularly of the two above mentioned cups from Phaistos, the one from the “western filling” and the other from the “sacrifical pit”. They have been analyzed with micro-Raman spectroscopy and with SEM microscopy: this is the first time that these types of archaeometric analyses are applied to this Minoan ware. We show here an example of the detailed information of the object and the results collected in the final tables after the analyses (Fig. 20).



Scheda	**03**		
Reperto	**84052**	*ID campione*	**84052**
Provenienza	Creta. Festòs, fossa dei sacrifici. Dono del Governo Cretese 1908 (ASBAT 1908 Mat. A/17: 9).		
Cronologia	**MMIIB**	*Fabbrica*	Impasto fine rossiccio
Foto del reperto			
Classe Tipologica	Tazza troncoconica monoansata.		
Descrizione del reperto	Orlo appena svasato, vasca con parete a profilo rettilineo e lievemente svasata, fondo lievemente incavo, ansa verticale a nastro sopraelevata. Superficie interamente ricoperta di vernice nera con decorazione sovradipinta: fascia bianca interna all'orlo e alla base, tratti orizzontali paralleli bianchi sull'ansa. Alla base dell'ansa e sulla faccia opposta ricorre un motivo spiraliforme "a girandola" con palla piena arancione con tre petali da una parte e tre petali dall'altra. Sul corpo corrono due fasce a ovoli (o dischi pieni) con sovradipinta una linea in rosso vino, ondulate in modo che lasciano un intermedio spazio a occhio dalla parte dell'ansa e sulla parte opposta. Negli spazi liberi presso l'orlo, triangoli a lati ricurvi, entro i quali sono risparmiati spazi rotondi. L'esemplare mancante di vari frammenti è stato restaurato più volte. Decorazione poco visibile. H. 8,8; Ø orlo 10,2; Ø fondo 6; sp. parete 0,3, sp. ansa 0,4. (*Fratini 2009, catalogo no. CR. 137 p. 61*)		
Colori Identificati e Misure colorimetriche	*Munsell*	*Sistema CIELAB 1976 - SCE*	
	bianco 5YR 8/1; nero 5YR 3/1-3/2; rosso 10R 3/4; arancio 2.5YR 6/8	**nero** L28,19 a3,00 b3,23	**rosso** L 30.93 a5,72 b6,97

Fig. 20 – Partial example of data collected after the archaeometric analyses on cup CR. 137 (T. Fratini, PhD Thesis, University of Florence 2012).

Conclusions

As this paper has shown giving an account of a representative part of a Cretan collection held by Italian museums and virtually included in a digital and on-line explorable display, the MUSINT project has been

[16] See our contribution in TUCCI, CINI, BONORA, NOBILE 2011.

intrinsically multidisciplinary, requiring the convergence of several areas of expertise as archaeology, history, multimedial communication, three-dimensional survey and modeling, free-hand drawing and computer graphics, archaeometry.

The integration in this structured informative and educational system of a large number of accurate and reliable 3D digital models, and of substantial descriptive textual, cartographic and photographic documentation, recreates the historical context for each finding.

Interaction on the Web, and probably in the next future also on stand-alone interfaces situated in the actual physical museum spaces in Italy, will be a fundamental teaching aid to make users understand and access the reconstructed provenance environment and relocate culturally and physically distant findings where they once belonged.

In this way it will also be possible to recover the urban, social, political and economic environment of Bronze Age settlements in all areas of interest (Greece, Crete, Cycladic islands, Rhodes and Cyprus).

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Hypotesis for the virtual anastilosis of the main chapel of the iglesia de Los Desamparados de Les Coves de Vinromá

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Abstract: The Desamparados’ Church of *Les Coves de Viromá* (Castellón, Spain) belonging to the Order Monchs of the Calatrava was built during the XII century. The Church was constantly changing, and in the XV and XVI centuries was when the ribbed vaults were built. Nowadays it appears as small church characterized by the typical gothic vaults despite its former Romanic shape. For many centuries it was the only church of Coves de Vinromá, but during XVIII century it was built a bigger church (Iglesia de la Asunción) that became the new religious center of the town; anyway the excellent stereotomic solution adopted for it construction still appears as one of the main heritage of the Comunidad Valenciana. During the Spanish Civil War the main chapel of the church was used as a pit for a machine gun and it was intentionally destroyed using dynamite: the consequence was that the nine keystones and great part of the voussoirs have fallen on the soil of the chapel. The aim of this research was to make a virtual anastilosis of the fallen pieces using laser scanner survey for both keystones and parts of the arches still remaining in their place. The whole methodology is based on the data acquisition of structural elements and architecture by means of different scanner laser equipments (with different sampling and accuracy) and then a second phase focused on data integration by means of different programs.

Thanks to reverse modeling techniques it was possible to determine the bend radius of the fallen voussoirs of the main chapel’s ribbed vault, and also the different angles formed by the keystones.

In that way great part of the ancient shape of the ribbed vault came up as the result of an analytic process that disproved another reconstruction hypothesis base on a traditional survey during the eighties.

For this vault’s study, apart from the laser scanner, it has been used a more tradicional methodology, consisting in analizying similar vaults belonging to Comunidad Valenciana.

The virtual anastilosis is one of the main output of this research conducted inside the Master Oficial de Conservación del Patrimonio Arquitectónico as a final thesis. In the future it will possible to use this study as the base for the real restoration of this ribbed vault.

Keywords: Laser Scanner Survey, Data intregration, Virtual anastylosis, Spanish Medieval Architecture.

Introduction

This work forms part of a line of research at the IRP/UPV whose first results were materialised in a master’s thesis (MARTÍNEZ-ESPEJO 2010). It goes on from an earlier study carried out by architects Francisco

Grande Grande and Ignacio Gil Mascarell, on Los Desamparados Church in Les Coves de Vinromá (Castellón), prior to its restoration. That study put forward a hypothesis on the design of the vault in the main chapel, which was not actually put into practice. The level of detail determined by the traditional procedure then used did not allow an accurate observation of particularities (small deformations, rises in the spring lines or drops in the centres of the radii of the diagonal arches). This has now indeed been possible with the new technologies, whose relevance has been proven.

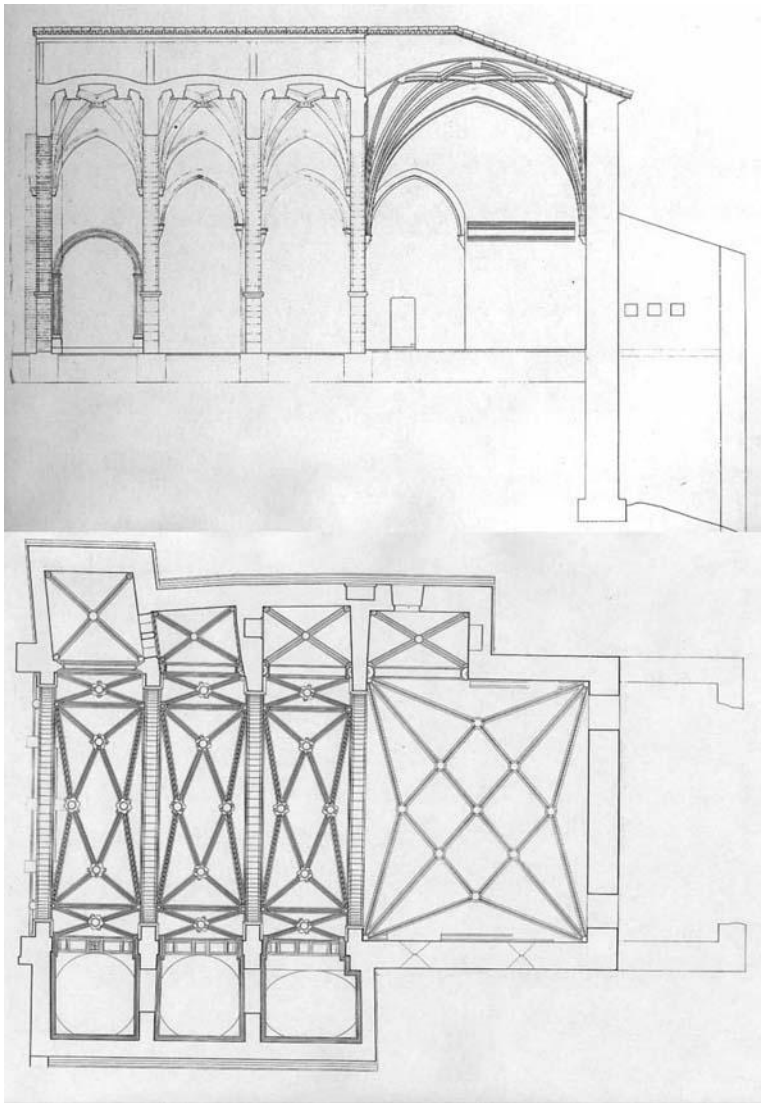

Fig. 1 – Ground plan and longitudinal section of Los Desamparados church, with the projection of arches and ribs of the vault and the hypothesis of the design of the Main Chapel Vault, as put forward by Francisco Grande Grande and Ignacio Gil Mascarell (1985).

The objective that was set in this task was the virtual restoration of a vault in this 16th century church. The approach implemented for reaching the design hypothesis was grounded on a typological study of similar vaults of the same age and area (vaults from the north of Valencia Region in Spain).

The procedure was designed to take advantage of the potentials of these new technologies, seeking the greatest possible proximity to the genuine historical vault which collapsed during the Civil War. This was

possible thanks to a good deal of the original pieces still being found on the site and recovered from among the rubble.

The conclusive result of the work is a three-dimensional model close to the virtual anastylosis of the vault, in which mainly advanced methods, and also traditional methods, were used.

Desamparados Church in Les Coves de Vinromá

Based on the aforementioned earlier studies (GRANDE GRANDE and GIL MASCARELL 1985) the hypothesis assumed was that the church had been built in four phases. The first of these was in the 13th and 14th centuries, and the sections corresponding to the third and four chapels on the Gospel side, the diaphragm arches and the walls forming the presbytery still remain from this stage. The second phase, which would cover the 14th and 15th centuries, involved the building of the first and second chapels. In the third phase, in the 16th century, the vault of the central nave and the presbytery were built, with ribs of the same profile and same iconography in the keystones and the spring lines. There was finally a fourth phase taking place in the 17th or 18th centuries, with the building of the chapels on the Epistle side, with panels, continuous imposts, sail vaults, sgraffito work, etc.

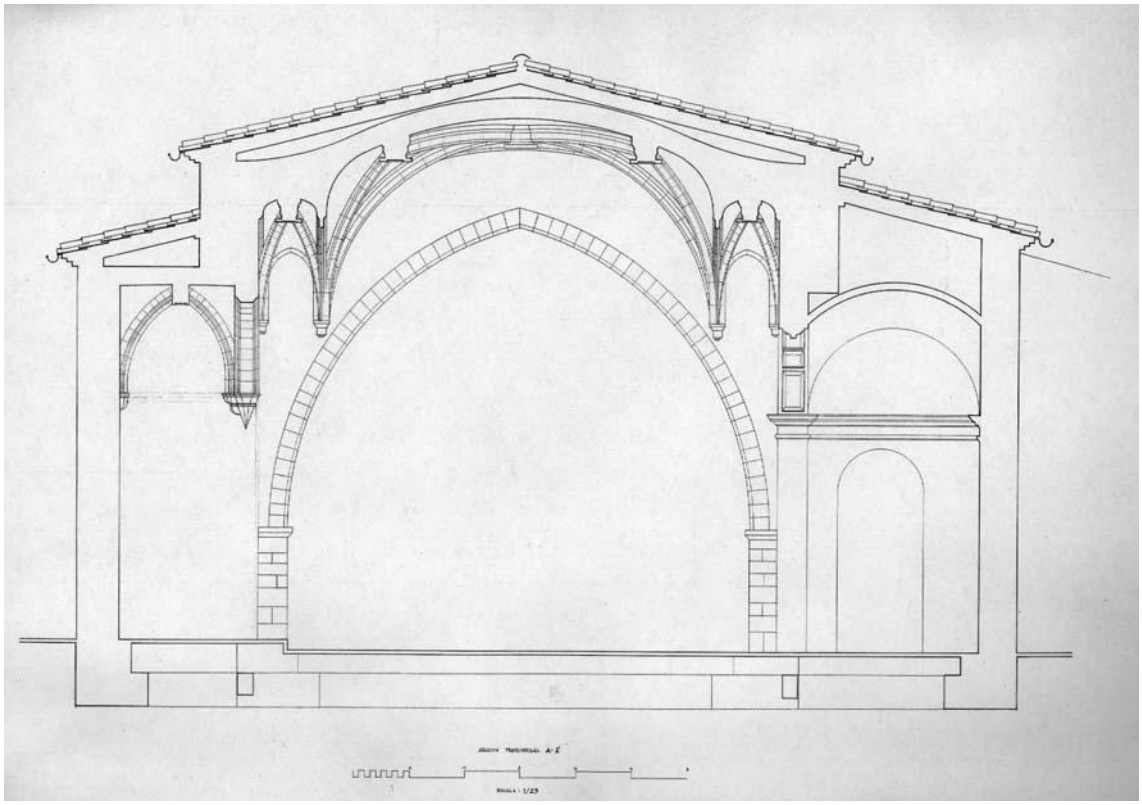

Fig. 2 – Cross-section of Los Desamparados church in Les Coves de Vinromá according to the plans by Francisco Grande Grande and Ignacio Gil Mascarell (1985).

The construction abutted the main wall at its head. This was very probably originally one of the so-called "Reconquest" churches, with a rectangular ground plan, diaphragm arches and wooden gable roof. This type of roof must have been kept until the 16th century alterations, when it was replaced with ribbed vaults

(Zaragozá Catalá). The first church must have had four sections, apart from the presbytery, and very possibly a side access. From the second half of the 14th century three new chapels would be opened on the Gospel side, covered with simple ribbed vaults.

The doorway, facing south, was very simply made, with a semicircular arch, imposts and a filigree in a canopy. When the section where the doorway used to be was demolished no trace of this figure, very probably of the Virgin, was left. In its place, as can be seen from photographs taken at the time, there was a small, relatively modern, tile reredos, with the image of our Lady of the Forsaken, the last patron of the church. Part of the early mural decoration, partially restored by the Provincial Authority Service, can still be seen in these chapels on the Gospel side, though in a precarious state. This ornamentation is based on geometrical and floral patterns in ochre and vermilion shades and black. It is hard to date these to a particular age, though some of the motifs seem to be 15th century.

Alterations were made in the late 16th and early 17th century: the nave was extended at the head, adding a further section at the feet, opening three chapels beside the Epistle and replacing the wooden roof with vaults with simple ribbing and tiercerons.

Fig. 3 – Voussoirs of the ribs that once formed the vault of the presbytery, piled up on the ground (2010).

In the nineteen-twenties, probably as a legacy of the whole 19th century, the old church was practically abandoned, with a good deal of the items bearing witness to its medieval origins being preserved. What was left of these remains (images, altars, etc.), would finally disappear during the Civil War. Only a few of the liturgical items that had earlier been taken to the new church would be saved.

During the Civil War the church’s structure underwent considerable damage. A hole was made in part of the vault of one of the chapels to install machine gun nests and bombardments affected the entire presbytery and adjacent areas. Shortly after the war was over, the vault was blown up with dynamite to avoid what seemed to be the imminent danger of collapse, and its ruins were left on the site. Later, the church was for many years converted into an improvised dump for rubble, until its recuperation finally started in 1983. Today, though the last stage of the restoration work has still not been completed (the project being incomprehensibly broken off), the building has recovered a large part of its early structure, now turned into municipal premises used for cultural events.

Procedure

Using two types of 3D laser scanner with different resolutions (*HD Scan Station 2* by *Leica* for the architectural space, and *NextEngine 2020i 3D* for the archaeological remains) meant that exhaustive data could be obtained, with a detailed study of the keystones and the voussoirs found, as well as of the remains of the chapel itself. Three-dimensional virtual models were thus produced for both the preserved keystones and some typical voussoirs, as well as remains of the walls which once formed the presbytery.

Fig. 4. – Process of scanning one of the keystones with NextEngine 2020i (2010).

Using studies of the designs of similar vaults (NAVARRO FAJARDO 2006) and based on the recommendations of treatises written at the time (PALACIOS GONZALO 2005), it was possible to work from

a consistent hypothesis of the ground plan layout of the presbytery vault. The results of this combined study led to the steps required for achieving a preliminary outline of its horizontal projection:

A. Determination of the situation of the main (central) boss, at the intersection of the two diagonals.
B. Outline of a circle with its centre in the main boss and diameter in the diagonal. Drawing two inscribed tangential circles on the line containing the main boss according to the direction of the larger side of the rectangle.
C. By joining the corners with the centre of these circles the minor tiercerons were obtained.
D. The line parallel to the smaller side of the rectangle going through the main boss was drawn. Each half was split into three equal parts. In the outer thirds the keystones of the major tiercerons were found.
E. By joining the corners with these keystones the major tiercerons were obtained.
F. Lastly the four keystones of the tiercerons were joined, forming a rhombus shape of lierne ribs. Where these intersected the diagonal ribs the last lierne keystones were located.

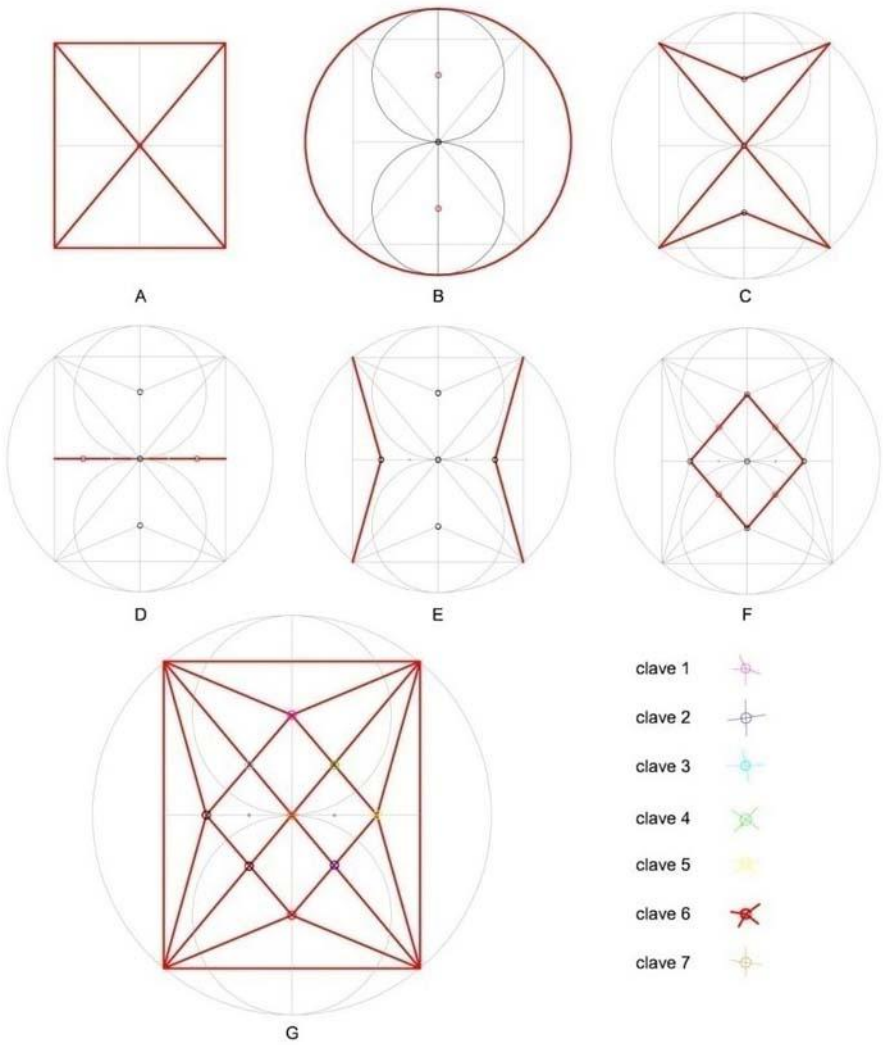

Fig. 5 – Steps in the preliminary geometrical trial for tracing the ribs of the vault in their horizontal projection.

This was how the first drawing of the hypothetical ground plan (7G) was obtained. The directions of the ribs meeting each of the keystones could be identified in this drawing and compared with each of the keystones found. This meant that they could be located in what we assumed to be their proper position and at the same time allowed us to make an initial verification of this first layout hypothesis with the consequent geometrical adjustments.

The next step was the shape of the arches. By studying the elevation of the wall of the main chapel, where the diaphragm arch is found, this was seen to have a radius of 5.41 m, while the traces of the side arch or formeret left in this same wall had a radius of 5.50 m.

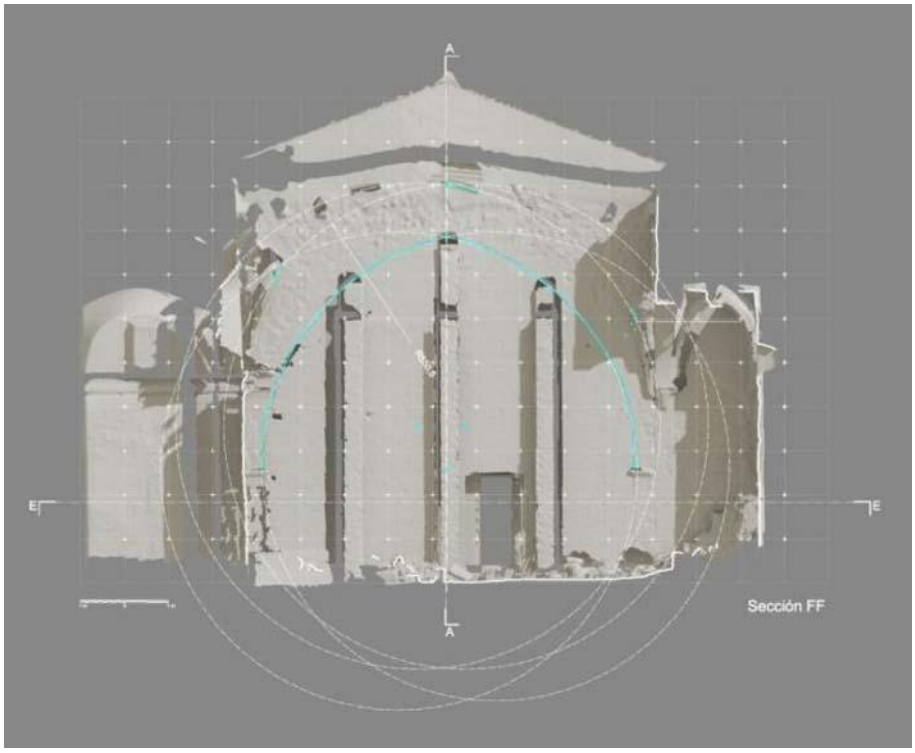

Fig. 6 – Study of the radii of the diaphragm and wall arches or formerets from the virtual model created in the survey (2010).

Through not being able to interpret their traces in the walls, as these are no longer appreciable, the hypothetical layout for the formerets of the smaller sides of the rectangle was established by using the same radius (5.50 m) and centre at one third, as had been verified for the formerets of the larger sides.

Apart from this, by making different sections at the spring lines in the cloud of 3D points obtained with the laser scanner, it was observed that the radius of the remaining arches (diagonal ribs and tiercerons) was found at from 5.50 to 6.00 m, and that the centres of the arches were not contained in the plane of the spring lines, but instead located on a lower plane, so that the diagonal ribs were not semicircular, but segmental arches.

After establishing the first hypothesis of ground plan and elevation layout of the arches of the former presbytery vault, the question still had to be considered in 3D to find out their full geometrical compatibility with the remaining keystones and voussoirs. This was done by using the virtual pseudo-anastylosis of the individually scanned items (keystones and voussoirs), in the virtual 3D space of the ruins of the chapel

picked up with the laser scanner.This three-dimensional hypothesis stemmed from a synthesis and in turn from the product of the different trials in a number of iterative steps moving from the general to the specific and vice versa.

The virtual vault was obtained as the result of an empirical study based on reverse-modelling techniques and interactive geometrical modelling (FANTINI 2008). The angles of incidence were obtained by means of a number of sections made in the 3D models of the chapel and of the keystones. By studying the traces of the spring lines and starting from the radii taken from certain voussoirs which are still integrated in the walls, a number of 3D designs were made until a solution was found which made the form conditions of each and all of the items compatible.

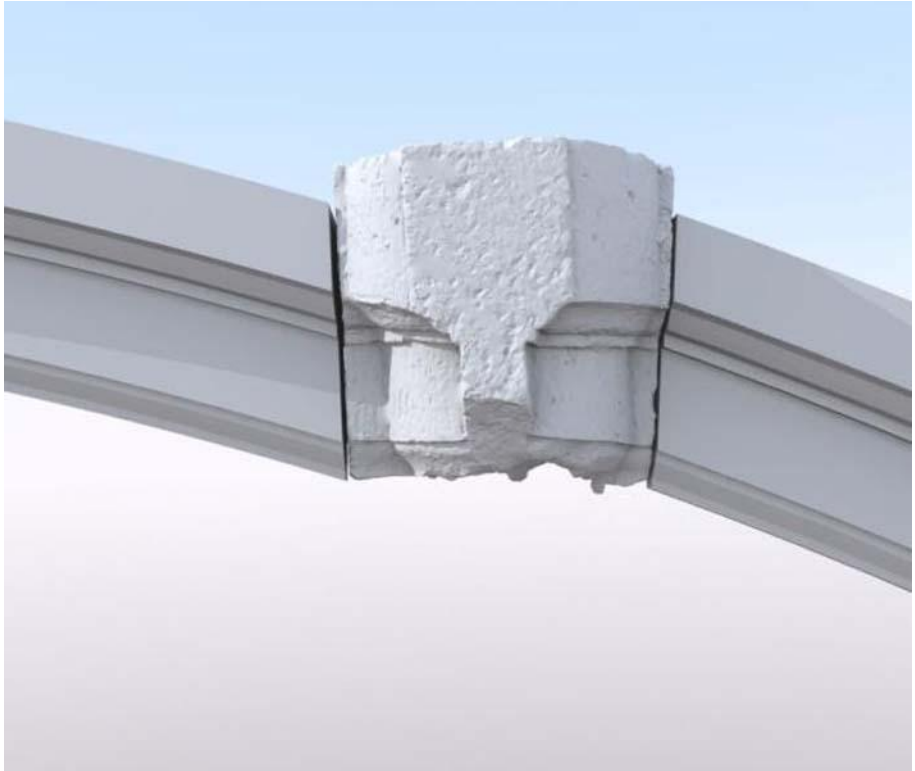

Fig. 7 – Detail of the vertical divergence of the trajectory of the diagonal ribs as these go through the lierne keystones (2010).

This check allowed certain inaccuracies in the initial hypothesis to be brought to light. The most relevant one involved the directions of the diagonal ribs which meet the lierne keystones which, although these coincided perfectly in the horizontal projection, did not match properly in the vertical projection. It was proven that the diagonal ribs, from the lierne keystones, kept the radius and direction on the ground plan, but not the trajectory in the vertical projection, which proved to move slightly linearly downwards, with no rotation. The lierne keystones would thus comply with a geometrical function in accordance between trajectories.

The result of this virtual reconstruction of the ancient vault of the Main Chapel produced one hitherto unsuspected piece of data as regards the general layout: the height of the main keystone of this chapel (much lower in this hypothesis than in the one formulated by Grande and Gil), was similar to the height of the longitudinal rampant line of the vaults forming the central nave of the church (11). This was probably a conditioning factor at the outset, established to be able to close off the whole church with a common roof,

which was quite likely to have ended in a flat terrace (a solution often implemented in the churches of that time in the area). This could have been the reason leading to lower the plane of the centres of the arches more than usual in respect of the plane of the spring lines. The downward displacement of the trajectory of the diagonal arches in the interior zone of the central rhomboid shape would also have contributed to this.

Results and discussion

The main contributions made by the work can be summed up as follows:

- This is a stellar ribbed vault with curved rampant line covering a rectangular and slightly trapezoidal ground plan area, its smaller sides being 7.79 and 7.80 metres long, its larger sides 9.33 and 9.49 metres and its diagonals 12.31 and 12.11 metres. The spring lines of the vault’s arches are located 4.082 metres from the ground, and the soffit of the main boss at 9.42 metres.
- The vault had 9 sustaining keystones (a central one and eight secondary ones), four formeret or wall arches and 8 ribs stemming from the keystones of tiercerons (two from each keystone). The vault had a rhombus-shaped lierne whose vertices were the keystones of tiercerons (four), with the four remaining ones being located at the intersection of the liernes with the diagonal arches.
- The documented voussoirs of the ribs of the vault that covered the main chapel which were found on the ground, recovered from among the rubble, whose inventory is given in the datasheets drawn up for this purpose, come to 212 items, described as follows: P (110 pieces), L (60 pieces) and G (42 pieces). The type P voussoirs corresponded to the tiercerons and the lierne, the L type were for the formerets and the G type the diagonal ribs. At first seven of the nine keystones forming the vault were located, although a more detailed examination showed that one of these did not belong to this vault, through the geometrical incompatibility with the layout of its ribs.
- The main boss is the only one of the keystones found that receives G type ribs on all its sides, for which reason it was deduced that only the diagonal ribs met this.
- Two types were observed among the remaining eight keystones: the 2P and 2G type which have the spring lines found two by two, which correspond to keystones which are located at the intersection between the diagonal arches and the lierne, and the ones that have a much larger horizontal angle than the rest, belonging to keystones of tiercerons, only with P type ribs. The curve and the angles between them were determined for these to be able to locate them spatially.
- The angles between the ribs reaching the keystones and the angles of the rib in respect of the vertical axis of the keystone were obtained with absolute accuracy from the data taken with laser scanner.
- Two formeret arches, one diagonal and two tiercerons, started out from each springer’s fork. The spring lines scanned have enabled determining the approximate radius of each of the arches forming the vault. This data enabled us to deduce that the centre of the radii was not located at the height of the spring lines, but on lower planes, the centres of the formerets being on one plane and those of the diagonals and the tiercerons on another. The plane on which the centres of the formeret arches are located is closer to the floor than that of the rest.

- Since the vault is not symmetrical, the formeret arches are not identical, but all of them nevertheless have the same radius, according to our hypothesis. They are all ogival and comply with the condition of their centres being at one third of the span.
- In the final hypothesis of the form of the vault, the hypothesis of the spherical cap is ruled out through incompatibility with the form conditions. The keystones have their vertical axis located perpendicular to the floor and in parallel to the walls (this detail is repeated in the other vaults in the central nave of the church). The radii found in the vault range from 5.50 to 6.00, and the radii of the formerets of the smaller side are equal to those of the larger one.

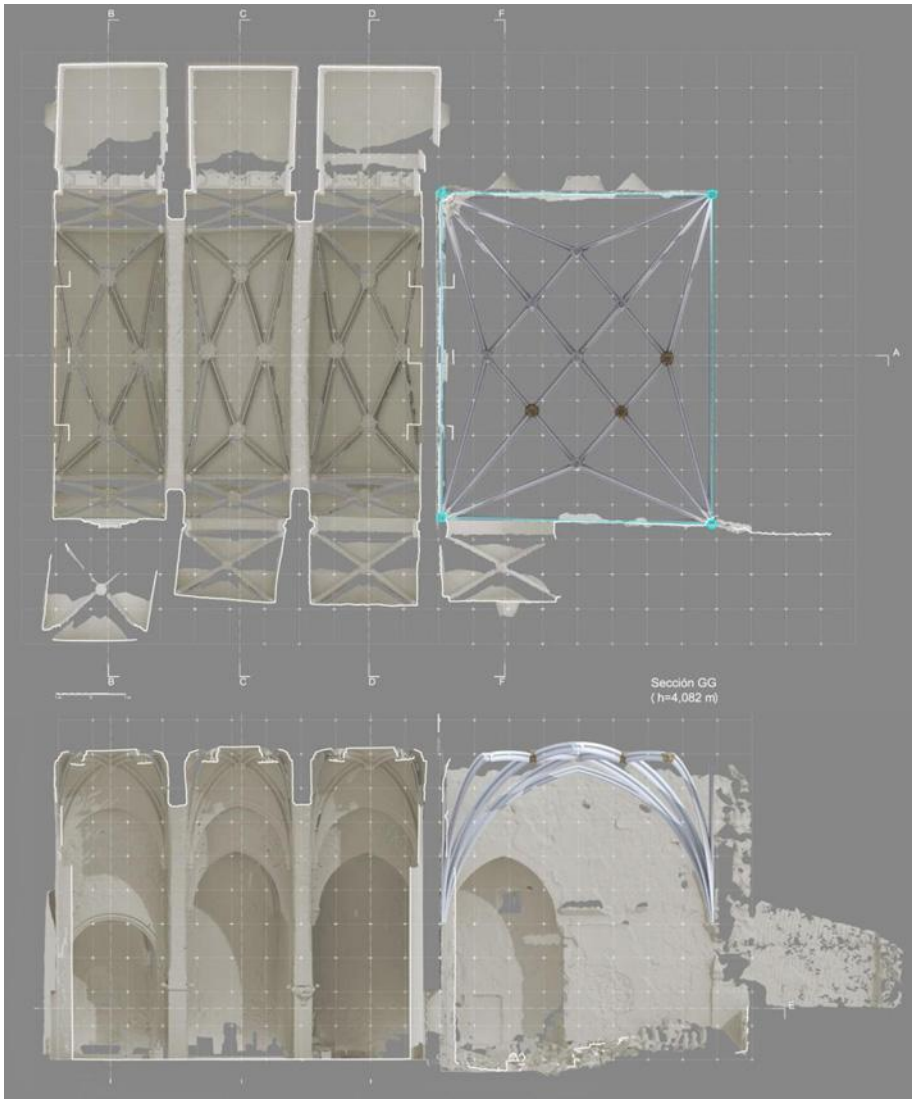

Fig. 8 – Lower ground plan and longitudinal section of Los Desamparados church in Les Coves de Vinromá, taken from the virtual model, incorporating the ribs of the presbytery vault, according to the final hypothesis stemming from the research (2010).

Conclusions

After a thorough examination of the vault the conclusions that can be drawn are:

- The laser scanner has enabled a revision of the hypothesis of the layout of the vault of the Main Chapel of the old Coves de Vinromá church, with a high degree of reliability. This constitutes a clear step forward, not only for obtaining data for the planimetric survey (a single scan produced a large amount of information that would have been hard to get from data taken directly) but also for verification of the restitution hypothesis.
- Obtaining reliable and accurate virtual 3D models of the real keystones has meant that a consistent and verifiable hypothesis could be put forward, by performing a recomposition process in the virtual space, equivalent to the procedure that would have been carried out in real reconstruction work.
- Apart from the references to the studies made on the vault, the precision of the laser scanner meant that it was possible to observe further details which could be the subject of later studies. For example, in the centre of the keystone, the trajectories of the ribs do not coincide in their horizontal projection (this fact is confirmed in the seven keystones scanned and studied).
- This study proves the usefulness of the surveying technique based on 3D laser scanning for virtual plotting of complex geometries proper to historical structures like gothic vaults.

Although this study may in theory set out from work on a single vault, it furthermore allows making the assertion that the laser scanner is an irreplaceable tool in research today and in the preliminary studies for projects involving intervention on our Architectural Heritage.

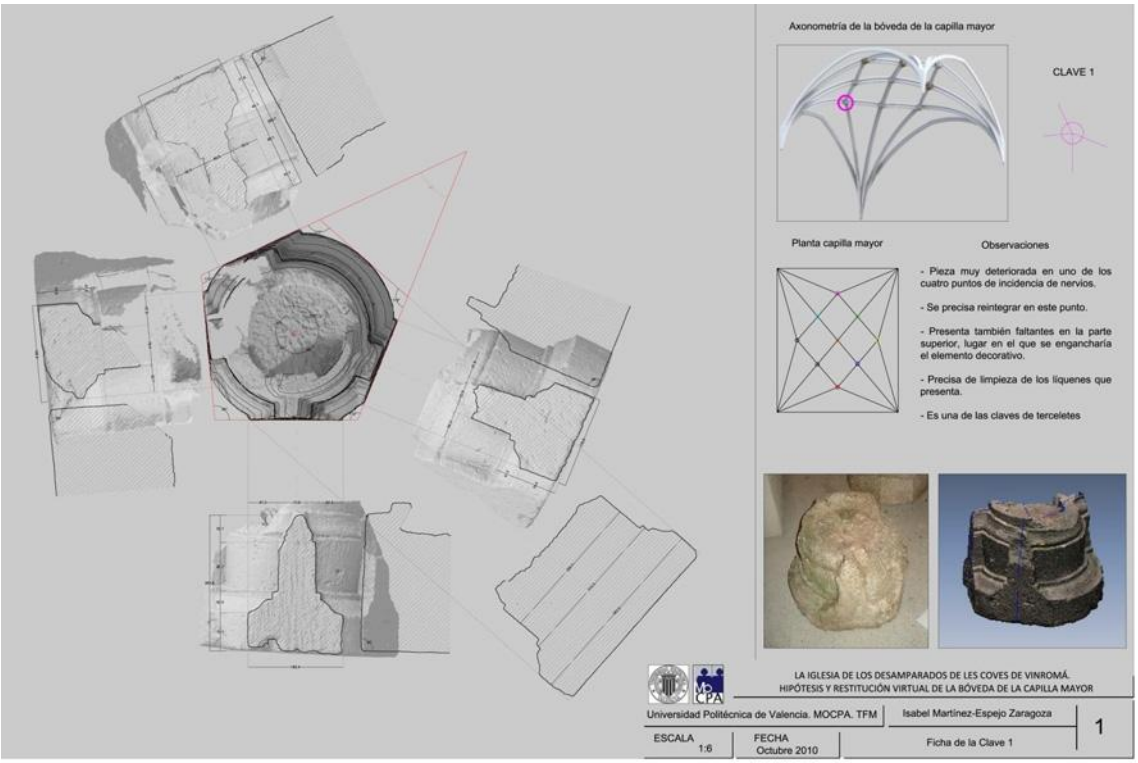

Fig. 9 – Model datasheet of a tierceron keystone (2010).

Fig. 10 – Virtual 3D model generated in order to verify the spatial geometrical compatibility of the pieces of vault ribs (2010).

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Matters of Integration and Scale: New Efforts in Magnetometry Data Management at a Late Neolithic Settlement Site in Hungary

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Abstract: In recent years attention has been drawn to questions of how best to integrate geophysical remote-sensed data sets with other sources of archaeological data. Though other archaeological projects in the southeastern Europe are increasingly incorporating multiple data sources, a holistic integration and interpretation is rarely achieved, with geophysical data commonly reduced to the production of images, wherein archaeological features are identified and geographically referenced. In contrast, the Körös Regional Archaeological Project (KRAP), studying the Neolithic-Copper Age transition in eastern Hungary, has developed a research plan that has sought to integrate multiple data sources (geophysical, satellite, coring, surface collection, excavation) from the inception of the project.

In the past two years KRAP has run a high-resolution magnetometry survey that has covered more than 20 ha of the Late Neolithic site of Szeghalom-Kovácshalom. Preliminary data processing, concurrent with surface survey and excavation, allows immediate integration into the evolving research design. Later data management incorporates the magnetometry results into a project-wide GIS, as robust and flexible raster and feature datasets, which then permits further re-evaluation and interpretation of these data in conjunction with data from other sources. In order to make appropriate analyses the magnetic datasets were manipulated in terms of scale and resolution, and though this inevitably obscured the identity of specific features, magnetic “hotspots” were preserved. These “hotspots” were correlated with data produced by the surface survey, and the different resulting datasets were assessed in terms of their ability and efficiency in delimitating the boundaries of the site and to draw conclusions with respect to settlement organization. Preliminary results showed the value of different approaches to magnetometric data acquisition and management to the understanding of a highly dispersed and previously unrecognized form of settlement organization.

Keywords: Geophysical, Hungary, Archaeological survey, Neolithic, Copper Age, magnetometry.

Introduction: Neolithic/Early Copper Age Settlement Organization – Transition & Changes in Habitation Patterns

Previously knowledge of the Neolithic Tisza and Herpaly cultures of Eastern Hungary and Western Romania (Hungarian plain and Carpathian basin) has been based on a limited number of surface surveys and systematic excavations that have been carried out in the region. The most recognizable Tisza settlements are tells or tell-like mounds, ranging in size from approximately 1 to 6 hectares (KALICZ & RAZKY 1987: 16). A greater number of single-layer, “horizontal” Tisza settlements are also known, ranging from 1 to 12

hectares in size. Horizontal settlements often occur in view of tell settlements, and it is theorized that these two types of settlement forms represent some sort of settlement hierarchy, but the relationship is not yet fully understood. Likewise, the Herpaly culture had characteristic tells located in or near watercourses so that they were surrounded, or nearly surrounded by water. These tells were also accompanied by adjacent horizontal settlements, though separated by water. Tisza and Herpaly tells are now known to be surrounded by fortification ditches (often 2 or 3 ditches). With little other evidence for violence in this period, it has been questioned whether the function of these ditches and palisades were practical (defensive) or symbolic. Much less is known about the subsequent Tiszapolgar culture of the Early Copper Age of the Great Hungarian Plain.

In Hungary, three Late Neolithic sites have been the subject of recent systematic geophysical surveys. At Hajdúböszörmény-Pródihalmon, a survey in 2008 discovered a system of multiple concentric circular ditches around the tell (RACZKY et al. 2010). The magnetometry surveys of Polgár-Bosnyákdomb and Polgár-Csőszhalom also focused primarily on the tell, and the identification of a system of ditch enclosures. The larger survey area at Bosnyákdomb though, was also used to explore a portion of the horizontal settlement, the full extent of which was determined by surface collection survey. The survey at Csőszhalom likewise uncovered a multi-ring-ditch system, including 4 gateways, and 62 houses as part of the outer horizontal settlement (RACZKY and ANDERS 2008). A much more limited experimental survey was carried out by DUFFY (2010: 251) at Bélmegyer 45 (a Gyulavarsánd site) and Tarhos 26 (an Ottomány site).

This pattern is not unique in the area and it has been also noticed by similar research project in the wider region extending to Romania and even Serbia. At the Late Vinča Culture site of Crkvine, in Serbia, a magnetometry survey in 2006–2008, covering just over 3 ha (about 20% of the whole settlement), indicated a well organized Neolithic settlement revealing at least 103 NNE-SSW oriented houses (CRNOBRNJA et al. 2009: 10–12). At the primarily Late Neolithic (Vinca culture) Romanian site of Uivar, a high-resolution (10 pT at 0,1 x 0,5m sampling) magnetometry survey was conducted over an 11 hectare area (SCHIER and DRAŞOVEAN 2004), focusing mainly on the area of the tell (again consisting of a series of ditches) and its immediate surroundings. Even more impressive are the results of the recent magnetometry survey at Cornesti-Iacouri (Romania) that has been reported in SZENTMIKLOSI et al. (2011) and shows the evolution of such settlements during the course of the Bronze Age. The particular site that is close to the Koros valley (near the Romanian-Hungarian borders) exhibits four enclosures (with the outer one being almost 6 km across), inside of which a dense occupation has been suggested. With sites of this extent, the potential of the geophysical survey of the sites becomes not only obvious but necessary (as the authors mentioned: "... small-scale excavations are ineffective due to the immense scale of the site, and larger-scale excavations, especially those cutting the ramparts, have major consequences for time and funding. Trying to locate smaller features without prior geophysical survey is like looking for a needle in a haystack." (SZENTMIKLOSI et al. 2011: 821).

For the past 10 years, The Koros Regional Archaeological Project (KRAP), which is running after a collaboration scheme among the Chicago Field Museum of Natural History, the Ohio State University and Munkacsy Mihaly/y Museum, Bekescsaba, Hungary, is investigating various Neolithic and Early Bronze settlements in the area of Körös Valley in central eastern Hungary, where hundreds of Neolithic and Copper Age (ca. 6,000–4,000 BC) sites have been located as the particular area was probably an important

wetlands crossroad. The goal of this long term campaign is to study of the establishment and development of agricultural settlements on the Great Hungarian Plain during the Neolithic and Copper, and analyze their evolution into much larger, fortified, tells and large horizontal settlements at the end of the Neolithic period and their subsequent abandonment and replacement by smaller settlements during the Copper Age, in terms of environmental and socioeconomic parameters (PARKINSON et al. 2010).

Fig. 1 – Satellite image from the Google Earth showing the spatial distribution of the sites that have been investigated through geophysical surveys under the KRAP program until today.

A major component of the KRAP research strategy is to carry out large-scale high-resolution ground-based geophysical surveys, which accompanied by further modules of KRAP project such as surface surveying, test excavations, coring for chemical analyses, topographic mapping, a.o., could contribute in the understanding of the formation of the tells and the evolution of the farming societies in SE Europe (YERKES 2010). Up to now, the internal organization of the tell at Vésztő-Mágor, two horizontal villages on low hills at

Körösladány-Bikeri and Vésztő-Bikeri, and a small single-occupation hamlet at Okany-Futas were investigated through geophysical prospection (Fig. 1). The same approach was used to study the fortification systems of the villages and the tell (SARRIS 2003; 2004; 2006; SARRIS et al. 2004a; 2004b; PARKINSON et al. 2004; 2010; YERKES et al. 2010). The latest exploration concerned the site of Szeghalom-Kovácshalom, the results of which survey (SARRIS and PAPADOPOULOS 2010; 2011) will be used for addressing the topic of the particular paper. Prior to the Koros Regional Archaeological Project investigations of 4 Early Copper Age settlements, this later period in the Great Hungarian Plain was known almost exclusively from studies of mortuary contexts (BOGNAR-KUTZIANI 1963; 1972; CHAPMAN 1997; DEREVENSKI 1997; MEISENHEIMER 1989; SKOMAL 1983). The stylistically more homogenous Tiszapolgar Culture was believed to have replaced the more distinct Late Neolithic Herpaly, Tisza, and Czoszhalom cultures.

The Archaeological Site of Szeghalom-Kovácshalom and Geophysical Exploration Strategies

Szeghalom-Sebes-Körös Mente (Szeghalom 108 or SZH-108) is located at the agricultural area to the north of the Sebes Körös River and SW of the village of Szeghalom. The site is easily accessible through a modern levee road above the Sebes Körös. A drainage ditch is running parallel to the levee to the south of the site. Szeghalom 108 is a representative Tisza settlement with some intrusive Bronze Age finds (ECSEDY et al. 1982: 161). The predominant Late Neolithic character of the site was also confirmed by a recent reconnaissance of the site that was carried out in 2008 by Salisbury and Pultz and who observed large concentrations of diagnostic sherds and daub (SALISBURY 2010). Salisbury carried out geochemical, magnetic susceptibility measurements and soil texture analysis to characterize the use of space and the type of activities in the area focusing on two specific locations (Loci 1 and 2) to the south of the tell. Locus 1 indicated two large daub scatters (probably related to structures' residues) and high values of frequency dependent susceptibility (indicating possible burning or heating activities), and Locus 2 indicated daub concentrations, and high values of Na, Mn, Zn, Ca and pH (SALISBURY 2010).

In the spring of 2011, the geophysical prospection survey expanded around the Szeghalom-Kovácshalom tell which is a flat-topped mount originally established by Neolithic farmers (Middle Neolithic Period -5300 B.C.). This was the 2nd phase of prospection carried out in the site, since from both the surface surveying and the geophysical surveying of 2010 it was indicated that the area was probably the locus of a “flat” farming settlement, together with other dispersed architecture. The geophysical prospection made use of both magnetic (Fig. 2) and GPR surveying. The GPR was used in an experimental basis to confirm the results of the magnetic survey and conclude on the signal that can be produced by daub made structures. Further modules of the research connected to the geophysical prospection campaign involved the use of aerial and satellite images and the experimental spectroradiometric measurements above suggested geophysical targets. The goal of the geophysical research was to map the subsurface architectural relics on the tell and in the area extending around the tell to provide additional information regarding the size of the site and the evolution of habitation patterns of the region.

The geophysical survey was conducted by the Laboratory of Geophysical-Satellite Remote Sensing & Archeo-environment of the Institute for Mediterranean Studies/Foundation of Research & Technology, Hellas (F.O.R.T.H.) under the auspices of KRAP. Within the two survey seasons, the magnetic surveys made use of high-resolution sampling, covering an area of 230,000 square meters, making it as the largest in extent high resolution geophysical survey that has been conducted in Hungary. The mosaic of the geophysical grids that was laid out for the purposes of the geophysical survey are shown in Figure 3.

Fig. 2 – Details of the magnetic survey that was carried out in the area of Szeghalom-Kovácshalom using Geoscan FM256 (left) and Bartington Instruments Grad601 (right) fluxgate gradiometers.

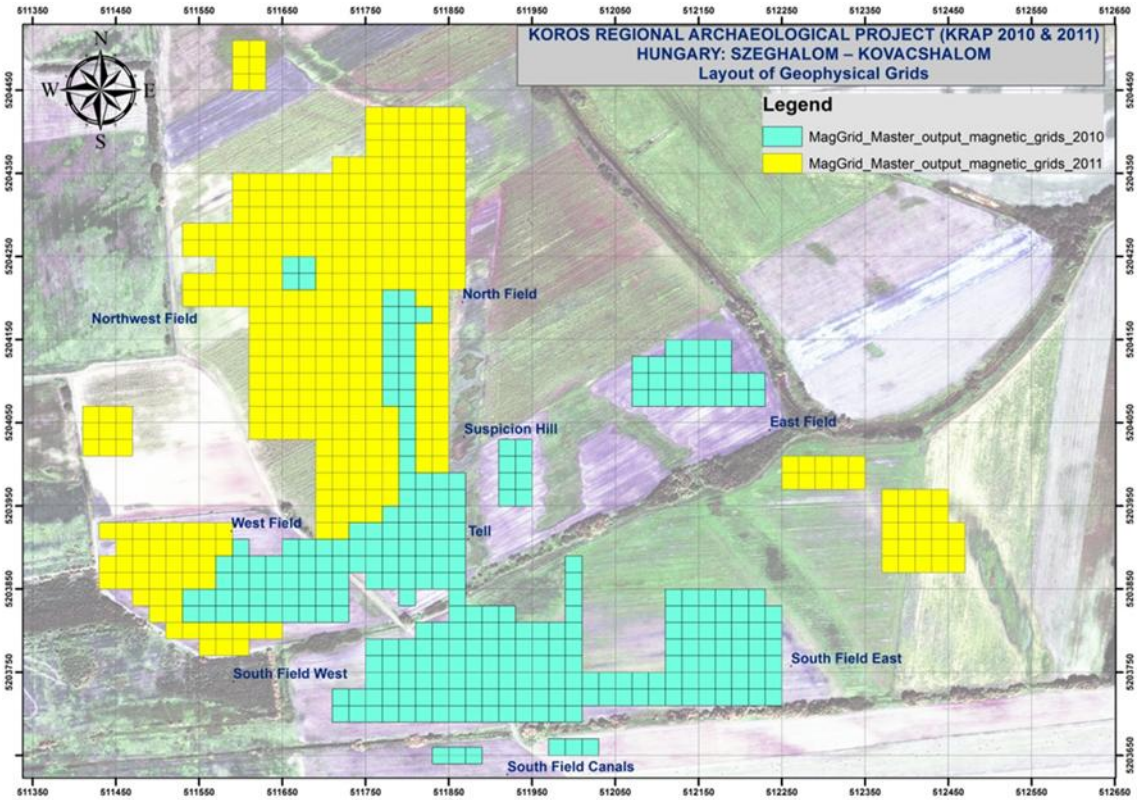

Fig. 3 – Layout of the geophysical grids around the Szeghalom-Kovácshalom tell that were covered with magnetic techniques in the campaign of 2010 (blue) and 2011 (yellow).

Both Geoscan FM256 and Bartington Instruments Grad601 fluxgate gradiometers (Fig. 2) were used for the measurement of the vertical gradient of the local magnetic field at Szeghalom-Kovácshalom. In this way it was possible to combine the measurements of both field seasons (20010 and 2011), process them together from the beginning and create a general map of the area that was used for the interpretation of the magnetic features. Both instruments produce comparable results and are independent of the season of the survey. Geoscan FM256 suffered more from instrumental drift and noise compared to the Bartington Instruments Grad601. The drifting of the particular measurements can be seen in the mosaic of the original magnetic data and it is still evident even after the application of grid mosaicing and despiking process. De-spiking of the data was necessary to smooth the results of the isolated extreme magnetic measurements in order to highlight the weaker magnetic characteristics. The construction of the mosaic of the individual grids was also essential for processing simultaneously them with the same processing parameters. In order to achieve this, the average values of the measurements of the individual grids were reduced to the 0-level base level in order to balance the signal's level differences originating from various balance procedures of the instruments and to make possible the construction of an enhanced image of the mosaic of the individual grids.

Matters of Integration and Scale

Even if the application of geophysical methods may need no explicit justification in an archaeological research program, as its contribution is quite obvious, still its input may have not been evaluated properly within the integral planning of an archaeological campaign. Furthermore, it has not been evaluated to the level that its contribution may have severe implication with respect to the archaeological interpretation. Geophysical prospection results are not limited just to the mapping of the subsurface targets and the estimation of their depth, extent and nature, but they can be explicitly used for the evaluation of the spatial extent of the site, the reconstruction of the paleo-environmental conditions and preferences of settlement, the analysis of the internal planning of settlement and the spatial organization of sites. In this way its contribution is an integral part of the theoretical concepts of archaeological research and can approach the same questions that a traditional surface survey may address (BENECH 2007; BENECH and HESSE 2007; THOMPSON et al. 2011).

Though other archaeological projects in the southeastern Europe are increasingly incorporating multiple data sources, a holistic integration and interpretation is rarely achieved, with geophysical data commonly reduced to the production of images, wherein archaeological features are identified and geographically referenced. In contrast, the Körös Regional Archaeological Project (KRAP), studying the Neolithic-Copper Age transition in eastern Hungary, has developed a research plan that has sought to integrate multiple data sources (geophysical, satellite, coring, surface collection, excavation) from the inception of the project. At Szeghalom-Kovácshalom, preliminary data processing, concurrent with surface survey and excavation, allowed immediate integration into the evolving research design. Later data management incorporated the magnetometry results into a project-wide GIS, as robust and flexible raster and feature datasets, which then allowed further re-evaluation and interpretation of these data in conjunction with data from other sources. In order to make appropriate analyses the magnetic datasets were manipulated in terms of scale and

resolution, and though this inevitably obscured the identity of specific features, magnetic “hotspots” were preserved.

Within the scope of KRAP, a systematic surface survey was carried out (supervised by P. Duffy) accompanied by surface collection and study of the corresponding material. The surface survey covered a larger area than the magnetic grids, on and around the tell, working within grid units of 10x10m or 20x20m. At the same time, a RTK-GPS survey was carried out through systematic scanning of the site by D. Riebe in order to capture the subtle topography of the site, which could have a severe impact in the settlement patterns of the past, as the slight differences in elevation may have influenced the seasonal habitation of the site. Additionally, the stratigraphy of the site and the variation of the depth of the cultural layers was possible to be depicted through coring (by R. Salisbury) at regular intervals along the site. The particular samples (about 250) were subjected to geochemical analysis and measurements of the magnetic susceptibility. Finally, a couple of test excavations were carried out (by A. Gyucha and R. Yerkes) for providing verification and feedback of the exposed features with the results of the surface survey and magnetic signals. The above activities gave the opportunity to have a number of complementary datasets resulting from various approaches, methodologies and resolution that could be compared to the results of the magnetic survey. It has to be mentioned however that the scope of the particular paper is not to interpret each one of the isolated anomalies, but rather to make a correlation between the general magnetic results and those arising from the surface survey.

From the analysis of the distribution of the surface finds, it becomes obvious that the largest concentration of the ceramics (Fig. 4c, 4e) appears on the area of the tell and SW of the tell, where the magnetic data pinpointed a dense flat settlement (Fig. 4h). A lower concentration of ceramics appears at a few more sections to the North, West and South of the tell, whereas the lowest concentration of ceramics is observed to the East (secondary soil deposition in the area due to flooding?). It is worth noticing that the high concentrations of ceramics outline the limits of the tell, but this is not the case for the daub concentration, probably because the foundations of the structures on the tell are lying on deeper soil strata. Furthermore, the daub concentrations (Fig. 4d, 4f) are more localized with respect to the position of the candidate structural remains that have been suggested by the magnetic measurements, while the ceramics concentration seems to be more dispersed around them as a consequence of the cultivation practices in the area. Actually, the relatively high concentrations of daub that are observed in the east sections of the site are the only indicators (in addition to the magnetic data) for the existence of structural remains in these specific sections of the site. Finally, high concentrations of lithic tools (Fig. 4b), that can be used as an indicator of the crafting activities of the settlement, appear mainly on the tell and to the S and SE of the tell. Therefore, it becomes obvious that it is not possible for the spatial organization of the settlement to be completely identified solely by the surface survey results.

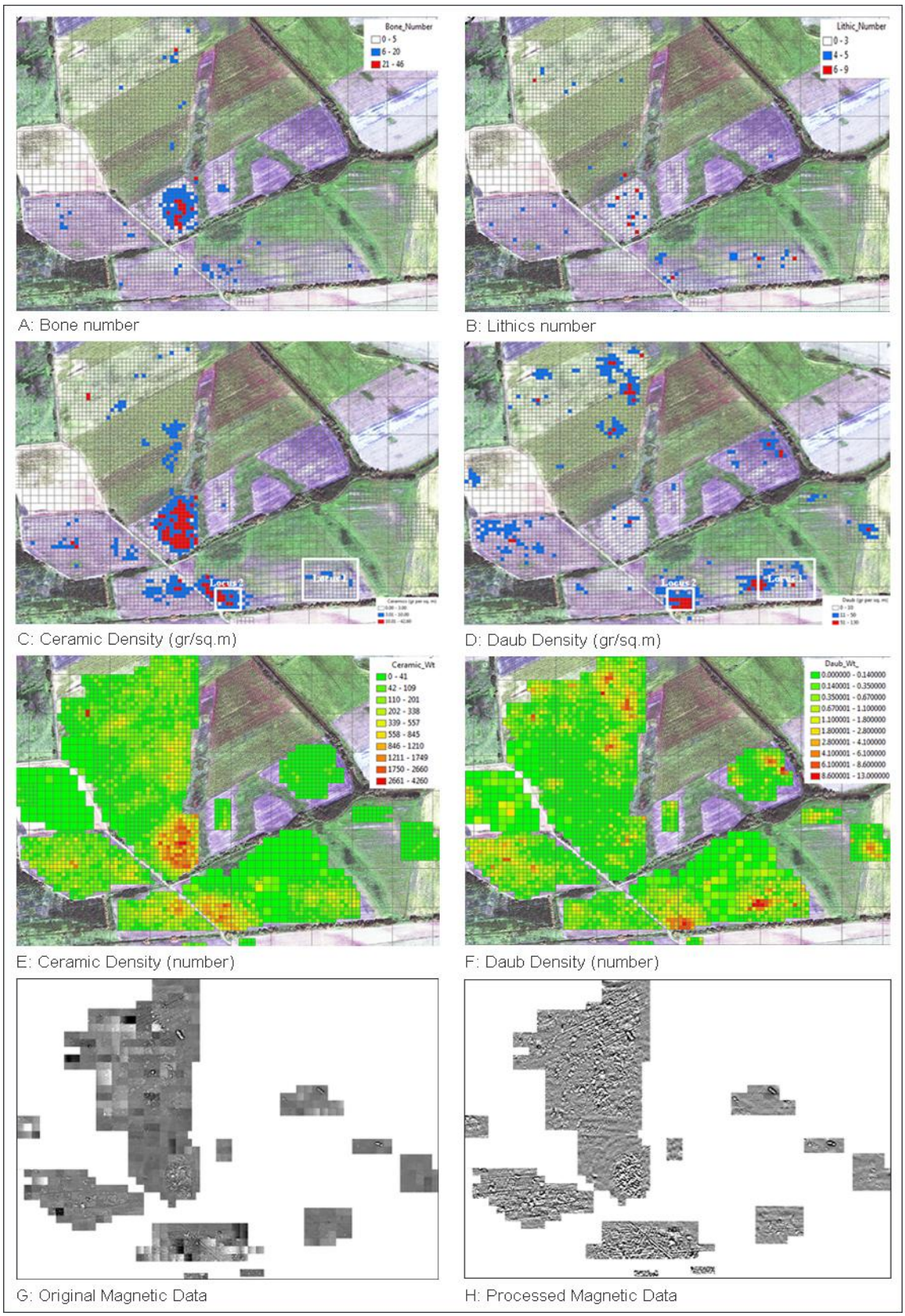

Fig. 4 – Results of the surface survey (A-F) and of the magnetic survey (G & H) at Szeghalom-Kovácshalom. A comparison of the various distribution maps indicates that only the ceramic and daub densities could correlate well with the processed results of the magnetic survey. The white squares in the maps of Ceramic and Daub densities correspond to Salisbury's Loci 1 and 2. The area coverage corresponds to 1060 (E-W) x 770 (N-S) m.

Turning to the micro-relief variations of the site, a correlation of the magnetic anomalies to the digital elevation model of the area is observed (Fig. 5). Even if the elevation in the region where geophysical survey has been carried out fluctuates within 4m in altitude, it seems that most of the candidate daub structures are located on the higher altitudes. These are also the regions where the more intense magnetic values were measured. The attenuation of the magnetic signals is noticed in the region adjacent to the north of the tell, to the north and east sections of the site, namely areas with a relative low altitude. Even if there are still a couple of intensive magnetic features to the very east section of the site, the rest of the candidate anomalies are of low magnetic signature (close to the background). Due to their relatively low altitude, these areas may have been more susceptible to flooding by the nearby streams (and even today they become the locus of water concentration) which would allow the repeated deposition of soils and erosion of the cultural layers, dropping the surrounding magnetic values close to background values.

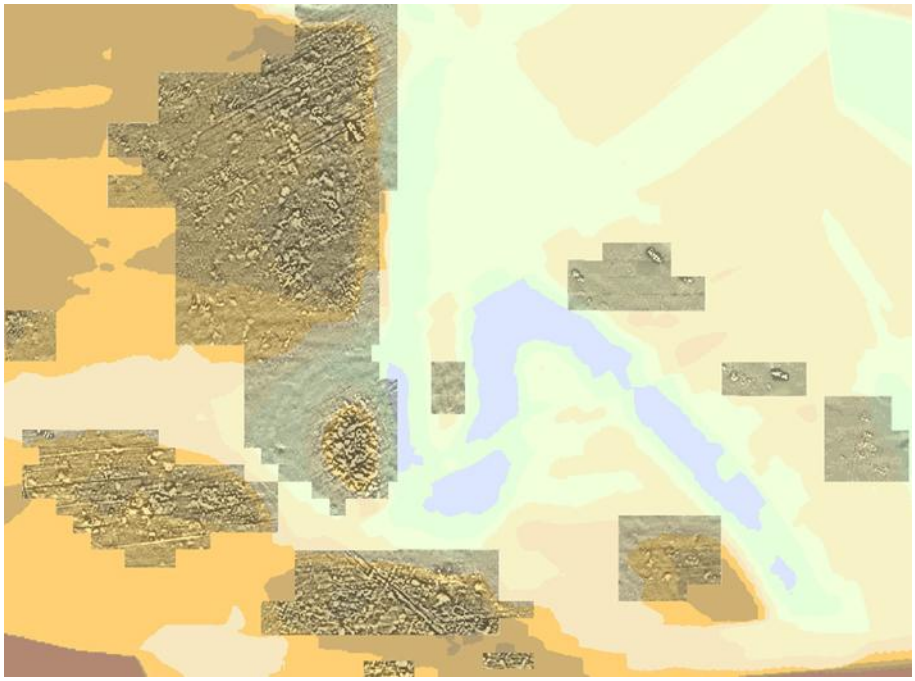

Fig. 5 – Superposition of the results of the magnetic survey on the DEM of the region. Most of the high intensity magnetic anomalies seem to be located at the local maxima of elevation. The local elevation difference within the site was within the range of 4m. Blue - green colors correspond to low elevations which designate the path of the river channels and the brown-orange colors correspond to the higher elevations.

Compared to rest of the datasets, the magnetometry measurements have been proved superior in pinpointing loci that contain residues of past activity and habitation (Fig. 5). The details contained in the magnetic datasets have been clearly the outcome of the high resolution sampling strategy and the type of processing that was applied to the magnetic data. An interactive batch processing was followed for all data, including despiking of extreme anomalies (based on the standard deviation estimation), equalization among transects and grids, high pass filtering and compression of the dynamic range of the magnetic values. Then the final images were exported and as raster files were rectified in GIS to be compared to the rest of the surface survey distribution maps.

In order however to make a more precise comparison of the geophysical results with the surface survey distribution maps, a proper adjustment of their resolution was made, so that statistical conclusions could be drawn based on similar datasets. With the intention of addressing questions related to the discrimination capability of the various datasets, a suite of neighborhood functions was applied. This type of neighborhood-based statistical functions allowed the statistical correlation with lower resolution datasets, removing noise and allowing a more rapid interpretation of the cultural disturbances in a more or less homogeneous background environment. The reduction of the resolution of the datasets was based on the actual measurements by creating a mesh of data points. For this purpose, geomagnetic maps were created by simulating a sampling of 20m, 10m, 5m and 2m, instead of the original 0.5m sampling (Fig. 6: A, C, E, G). It became obvious that even with the crude resolution of the 20m sampling, the magnetic data were promising in identifying the "hot" spots which were pinpointing residues of past habitation. Geomagnetic maps with a resolution of 10m were compatible to the information given by the daub density (Fig. 4F, 6C). Moving to a higher resolution, the 5m sampling geomagnetic data provided a much clearer definition of the spread of the anthropogenic residues, whereas the 2m sampling geomagnetic maps were capable to provide to a large degree the details that were described in the original datasets of 0.5m resolution. The application of unsupervised classification techniques through the ISODATA algorithm unified the isolated patches of magnetic values in each of the above cases and provided maps that could highlight areas of interest (Fig. 6: B, D, F).

The Getis-Ord Gi* statistic was also computed for the density of the daub (Fig. 6H) so as to obtain a picture of the spatial clustering of the daub concentrations with respect to the geophysical anomalies. A number of statistically significant hot spots (namely areas of high values surrounded by areas of similar high values) were located at most sections of the site (with the exception of the tell, where daub residues are expected at higher depths) where we have the larger concentration of candidate structural remains. In contrast, a cold spot in the clustering of daub concentration can be observed along an area to the NW of the tell. Actually, based on both the Getis-Ord Gi* statistic and the results of the magnetic survey that indicate a relative decrease of anomalies towards this direction, the particular area may designate the buffer zone that separates the flat settlement to the south from the more dispersed settlement to the north. In general, the map of the daub hot spot analysis can be correlated to the 20m sampling original or classified geomagnetic ap.

A similar correlation was noticed between the elevation (DEM) map, the daub distribution and the geomagnetic anomalies. Just by overlaying the simulated 10m geomagnetic data and the map of the Daub hot spot analysis, it becomes evident that the concentrations of daub and of the intensive magnetic anomalies are located on the relative high elevations of the region. This became also obvious from the application of principal component analysis (PCA) to the daub density, the ceramic density, the magnetic data (20m, 10m, 5m resolution), and the DEM, where the largest correlation coefficient (0.5) was indicated between the geomagnetic and elevation data. A smaller positive correlation coefficient was also noticed between the daub and the ceramic concentrations. The maps produced by choosing the first three components of the PCA, were able to identify even better the areas of interest (Fig. 7).

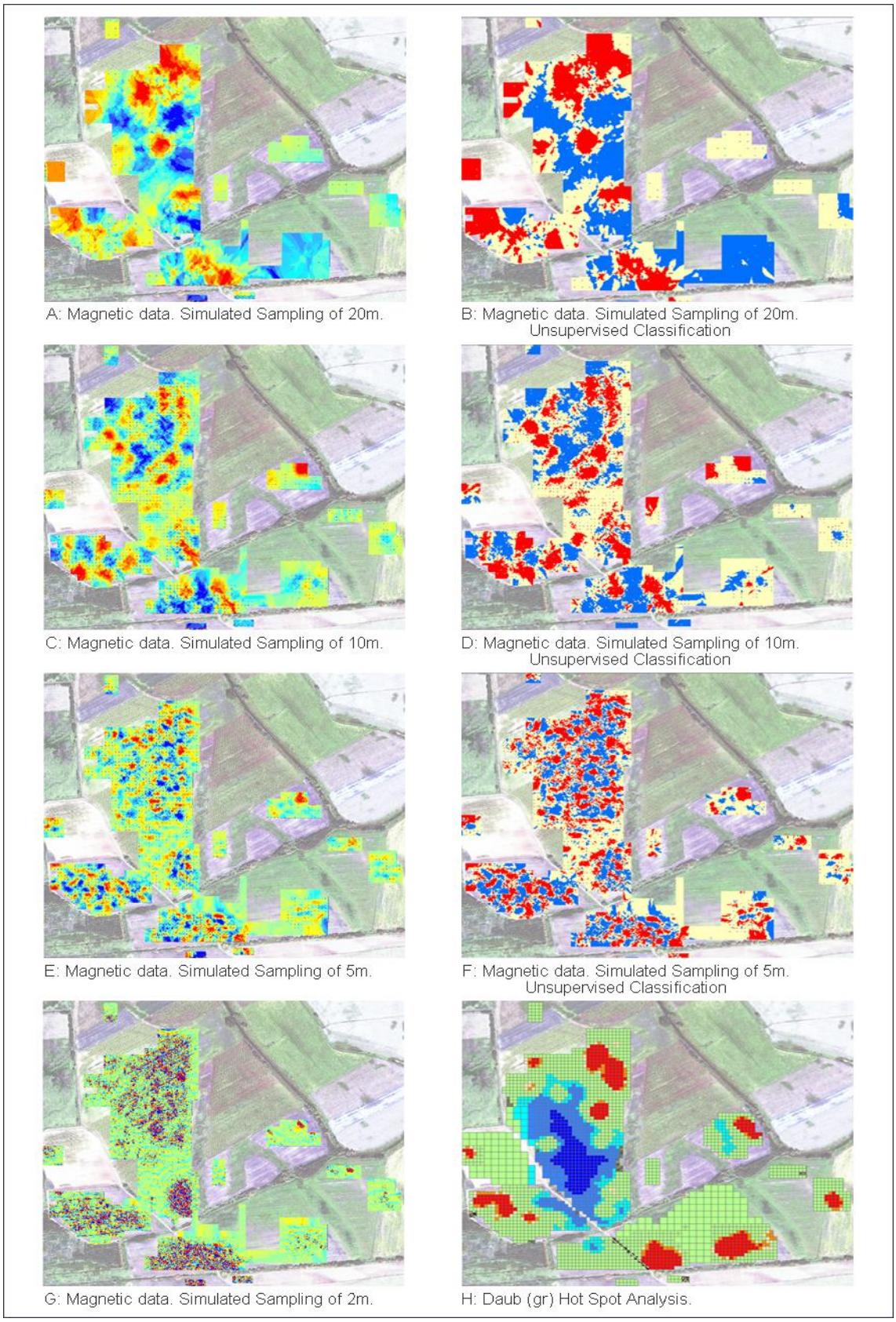

Fig. 6 – Results of simulated decrease of resolution of the magnetic measurements (A, C, E & G), together with the outcome of the application of supervised classification using the ISODATA algorithm (B, D & F). The 2m re-sampled data (G) resemble the original 0.5m resolution magnetic measurements. The daub concentration, being the most diagnostic of all the collected material, has been processed through the hot spot analysis (H) to be compared with the results of the unsupervised classification of the magnetic data.

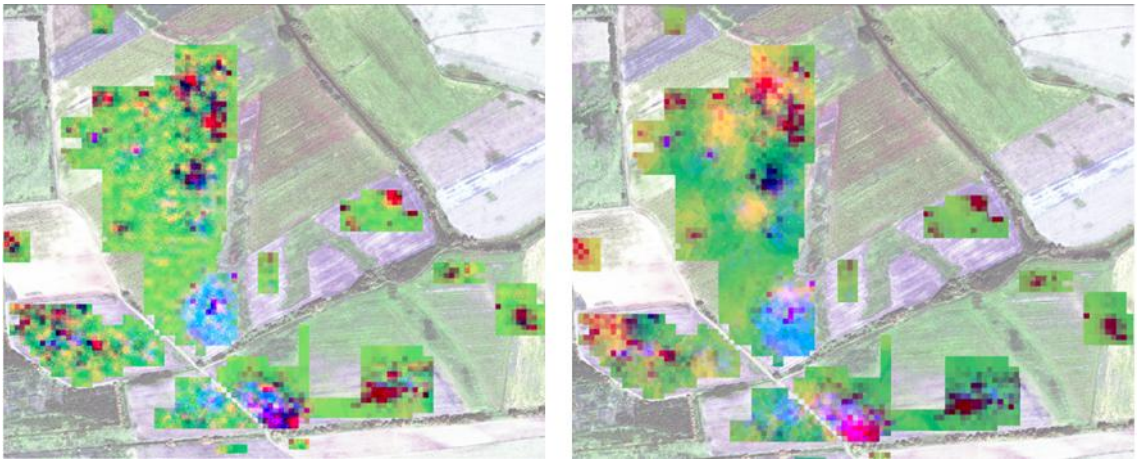

Fig. 7 – Application of the Principal Component Analysis (PCA) considering the daub and ceramic concentrations, the magnetic data and the DEM.

The above embrace the regional scale of the site. But what happens in a smaller scale? In a couple of sections that geomagnetic data pinpointed well defined structures (S81 and S36), soil samples were collected by R. Salisbury using an Oakfield hand coring device from a depth of about 25–40cm below the surface and they were subjected to measurements of the magnetic susceptibility. The sampling was different in each section, depending on the area coverage and it was 5–10m for the region around feature S81 and 2m for the region around feature S36 correspondingly. A dual frequency sensor MS2B (Bartington Instruments) was employed in the measurements of the soil magnetic susceptibility. Accurate measurements (in units of $1x10^{-6}$ cgs/gr) of the mass susceptibility were obtained in two frequencies (f_{low}=0.43KHz and f_{high}=4.3KHz). Each measurement was normalized for a mass of 10gr to be compatible with the initial calibration of the instrument. Both coordinates of the position from where the samples were extracted and the corresponding susceptibility measurements (in both frequencies) were recorded and processed with ArcGIS software. Measurements were carried out by E. Monahan, S. Cuba, Z. Siklosi, G. Bacsmegi & A. Gyucha at the facilities of the Lab of IMS-FORTH. As can be seen from Fig. 8, the magnetic susceptibility has produced compatible results with the high resolution magnetic survey. The 10m and 5m re-sampled geomagnetic data on one hand cannot provide the level of detail of the magnetic susceptibility, but at least they are of much more quality than the results of the surface survey (resulting just a few pixels in the concentration maps). In one way or the other, the re-sampled magnetic data could definitely pinpoint to the location of the candidate features. In one of the particular features (S36), a small excavation block was opened, to the north of the feature that was interpreted as a rectangular house (SARRIS and PAPADOPOULOS 2010). Two intrusive pits and a later burial, large concentrations of daub, a dark grey ditch/trench feature (probably residues of the house wall and wall trench), ceramics, human and animal bones and other artifacts were collected from the specific excavation trench (PARKINSON 2011).

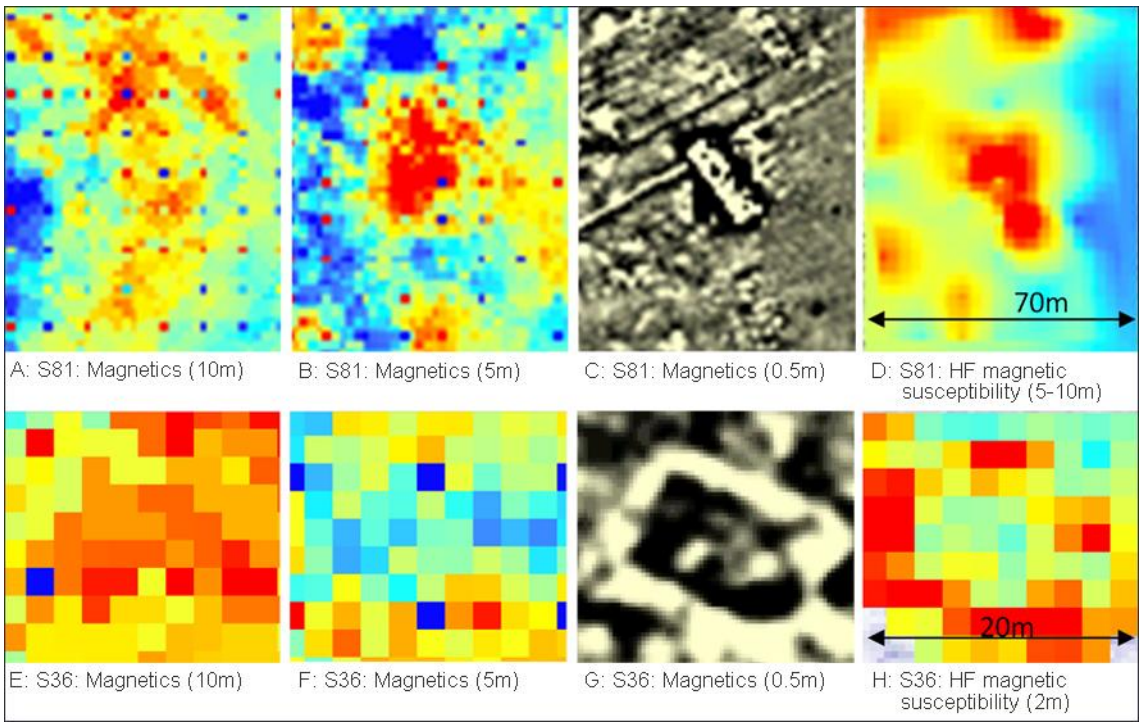

Fig. 8 – Comparison of the re-sampled and original magnetic data with the maps of the magnetic susceptibility (high frequency measurements) around the region of features S81 and S36 that were identified by the high resolution magnetic survey.

Fig. 9 – PCA synthesis of the coarse (5m) magnetic data, the surface survey results and the DEM.

Final Remarks

Based on the above it becomes evident that for the case of Szeghalom-Kovácshalom, the hotspots that were identified even with the simulated coarse sampling magnetic survey can be correlated with data produced by the surface survey, and the different resulting datasets are capable and efficient in delimitating the boundaries of the site and to draw conclusions with respect to settlement organization.

From the PCA synthesis of the coarse (5m) magnetic data, the surface survey results and the DEM, we can confirm almost all the most significant information regarding the internal spatial pattern of settlement (Fig. 9). Having also rectified the historical map of the site (black lines in Fig. 9), an empty buffer zone of 150m seems to exist between the tell and the dense habitation clusters, especially to the south, west and north of the tell. The fewer isolated clusters of features to the north, east and south-east suggest a more dispersed settlement in contrast to the thick clusters to the south and the west that imply a more organized type of habitation. Furthermore, the correlation of the habitat areas with the local maxima of the terrain implies that the occupation of the site was clearly influenced by the landscape morphology, and that small elevated "islands" were used for habitation in this wetland region.

Acknowledgments

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From traditional data to formal analysis. A proposal for comparing data from different survey methods in the coastal territory in southern Italy

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Abstract: This paper describes the construction of analytical tools for the analysis of territorial sectors of Poseidonia, Velia and Laos in order to reconstruct population dynamics and ways of organizing space. It focuses on technological tools, integrated with traditional examination techniques.
The research has provided an analytical work of evidence gathering and a problematic approach to the study of territory in view of integrating historical sources, archaeological and environmental and to test the application of quantitative analysis.
At this stage it is expected the implementation of a relational database and the acquisition of the data available with the aim of developing a system of spatial relationship It is not only to transcribe in related tables the data coming from the tradition, but to build an instrument useful to record the archaeological finds from different background and coherence in order to build the context of analysis.
As proposed, the project has provided the following schedule of work:
1) Construction of a *Geographic Information System* vector-based multiscale and multilevel
2) Construction of a *Data Base*:
   A) Formulation of a logical system for the management and analysis of archaeological sources
   B) Recording of archeological data: descriptive data and alphanumeric
   C) Recording of the nature of archaeological information: the spatial representation.Issues of scale, and symbols to vector
   D) Recording of the nature of archaeological information: the description of the time Issues of chronology and duration
The direction of research has led to the consideration and analysis of different nodes of the theoretical methodology of the archaeological investigation. In this area there is the problem facing the comparison and integration of data from different document management systems, each of which is defined by its epistemological status. The ultimate aim is to propose a multi-dimensional story that weaves its laws with those of space and depends on this.

Keywords: Database; Landascape Archaeology; GIS; Cultural Heritage.

Introduction

This contribution concerns a PhD research on the population dynamics of the territory between the Sele and Lao rivers. The territory includes the southern part of Campania and the northern coast of the Calabria region (Fig. 1).

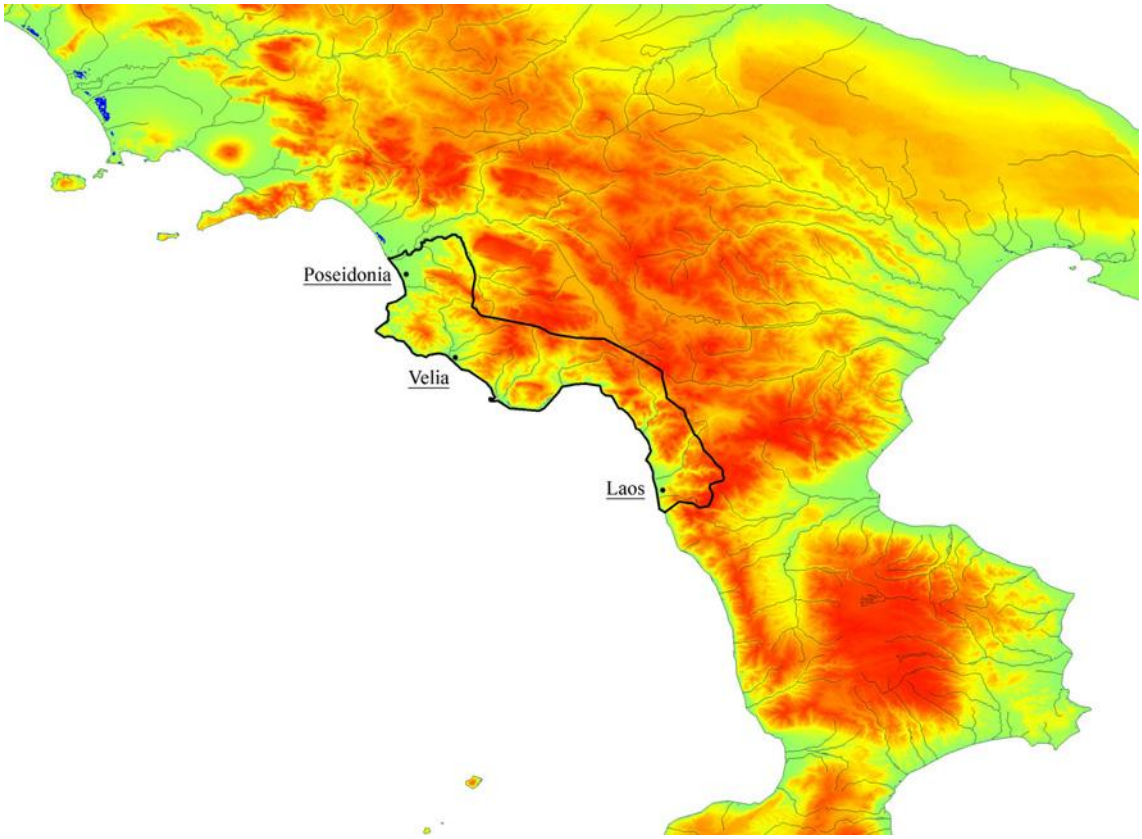

Fig. 1 – The tract of the coastal area of southern Italy included in the study.

The territorial sample does not dial an indistinct area. A macroscopic differentiation consists of the structural characteristics of the three cities that populate this area: Poseidonia, Velia and Laos The archaeological documents available reflect the land use just partially, in terms of exploitation of the basin, of settlement area, and of a place of contact and development.

According to an established pattern, Poseidonia is an agrarian *polis* (GRECO 1979; GRECO et al. 1987; GRECO1992; LONGO 1999; CIPRIANI 2002), Velia is a commercially-oriented city (GRECO 1975; BENCIVENGA TRILLMICH 1990; MADDOLI and STAZIO 1990; GRECO and VECCHIO 1992; DE MAGISTRIS 1995) and we know too little about the oldest settlement of Laos to be able to insert it in one of two classifications (GRECO and GASPARRI 1995; GRECO 1996; LA TORRE 1999). We know however, that it was the seat of the sybaritic people, who lived there after the destruction of their *polis*.

The tradition of the historical, topographical and archaeological studies is very wide and gives us a methodological framework of numerous systems, based, in most cases, on non-systematic investigations, without any analytical and quantitative level, with the exception of recent stratigraphic excavations and surveys (Fig. 2).

The common point is the absence of a generalized system of definition about what should be considered a *site*, an activity area, or, especially, a settlement. The recording unit and the analitical entities, on which historic summaries are set, are not explicitly defined. Neither the information about the spatial characteristics of the individual discoveries are determined in a methodical way.

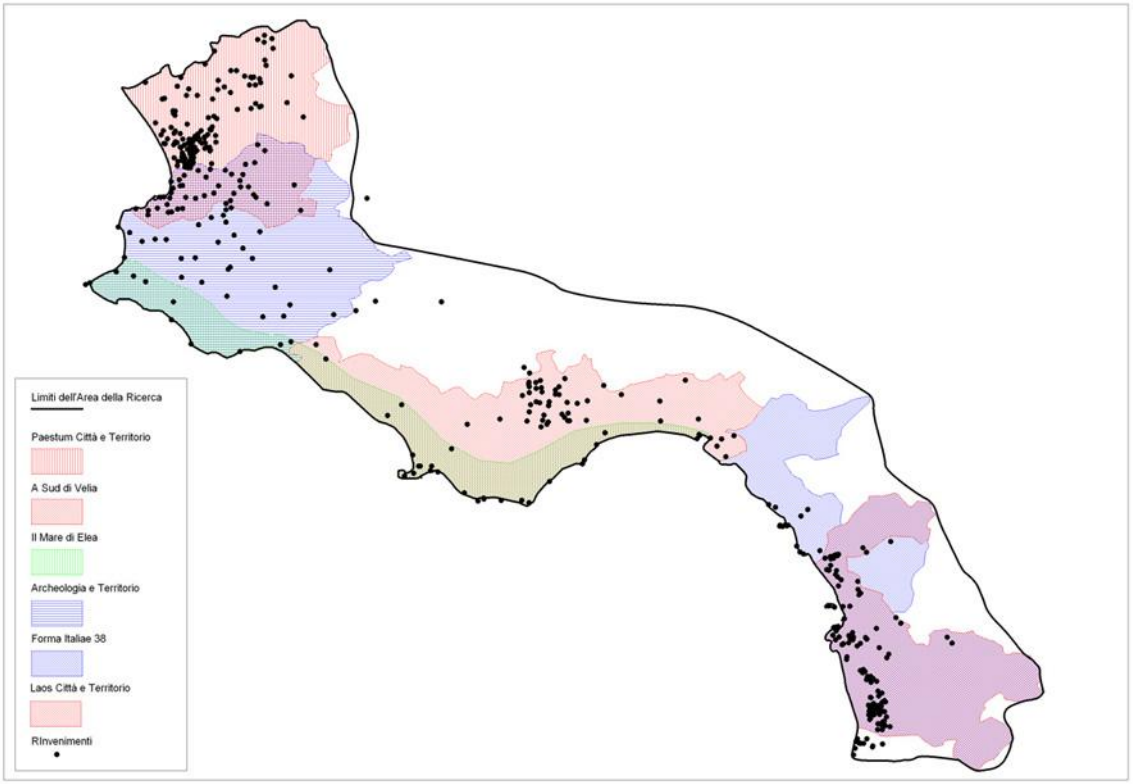

Fig. 2 – Distribution of traditional archaeological researches. Each hatched region represents a territorial study.

Often, the "only" presence of a material evidence in any place and in the form of any structure and composition creates a significant document. In many cases, the premises of topographical works have an historiographical purpose, such as the relationship between city and countryside, between *polis* and *chora.* For these reasons, the temporal limits are defined according to the chronological range in which the colonies lived and those geographical are based on the portions of their areas of immediate relevance: two variables necessarily in relation to historical events.

On this basis, we pose some problems. First, the uncertainty of the spatial boundaries of *chora,* often defined on the basis of literary sources. Secondly, the temporal limits of the investigation, nestled between the date of the founding of the colonies and their results are a sort of arbitrary extraction of information from a larger basin of knowledge. Finally, the collection and reading of data require to be directed to the evaluation of historiographical issues.

Features of the traditional approaches

In this research, I assume the specificities of each document in order to verify its information assets, its object and each of its limitation. You can not use data without fully understanding the cognitive value. It means origin, purpose and degree of approximation (Fig. 3).

The outcome of the traditional works consists of small-scale series of maps, 1 to 25,000 or 1 to 50,000 that show the distribution of archaeological evidences, organized according to typology and chronology (Fig. 4).

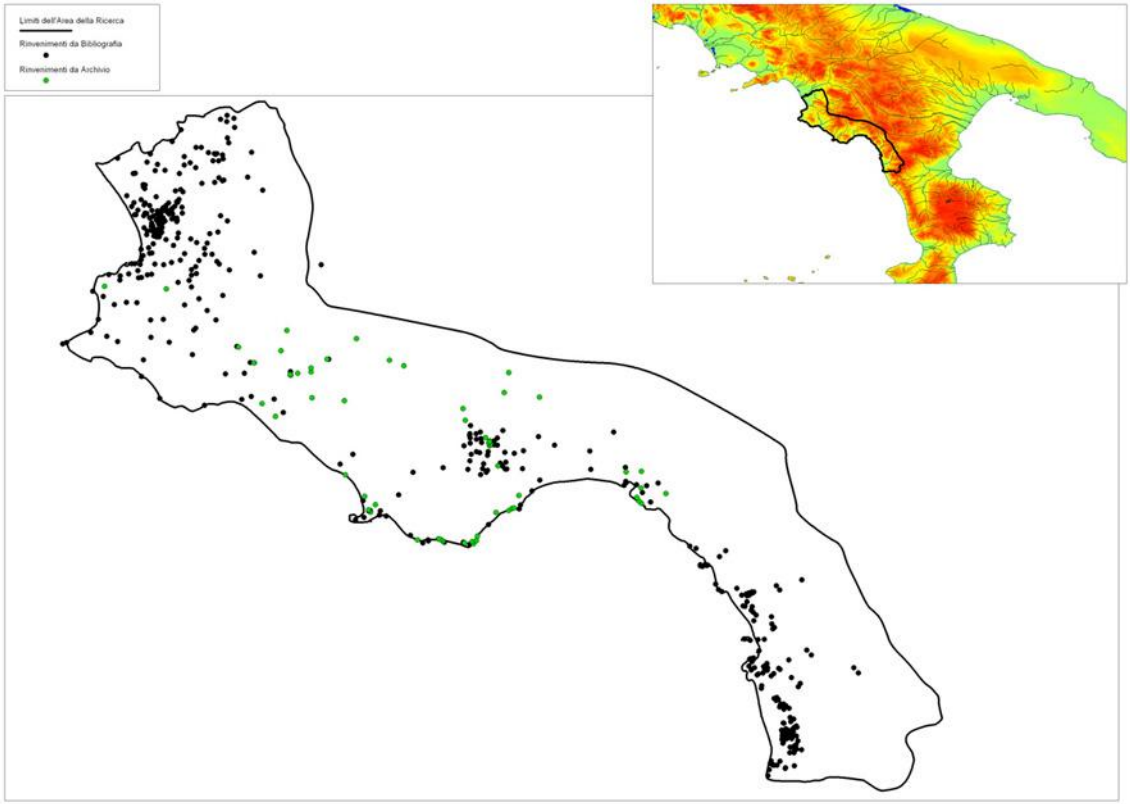

Fig. 3 – Distribution of archaeological evidences according to the traditional archaeological researches. Each dot is an unclassified discovery.

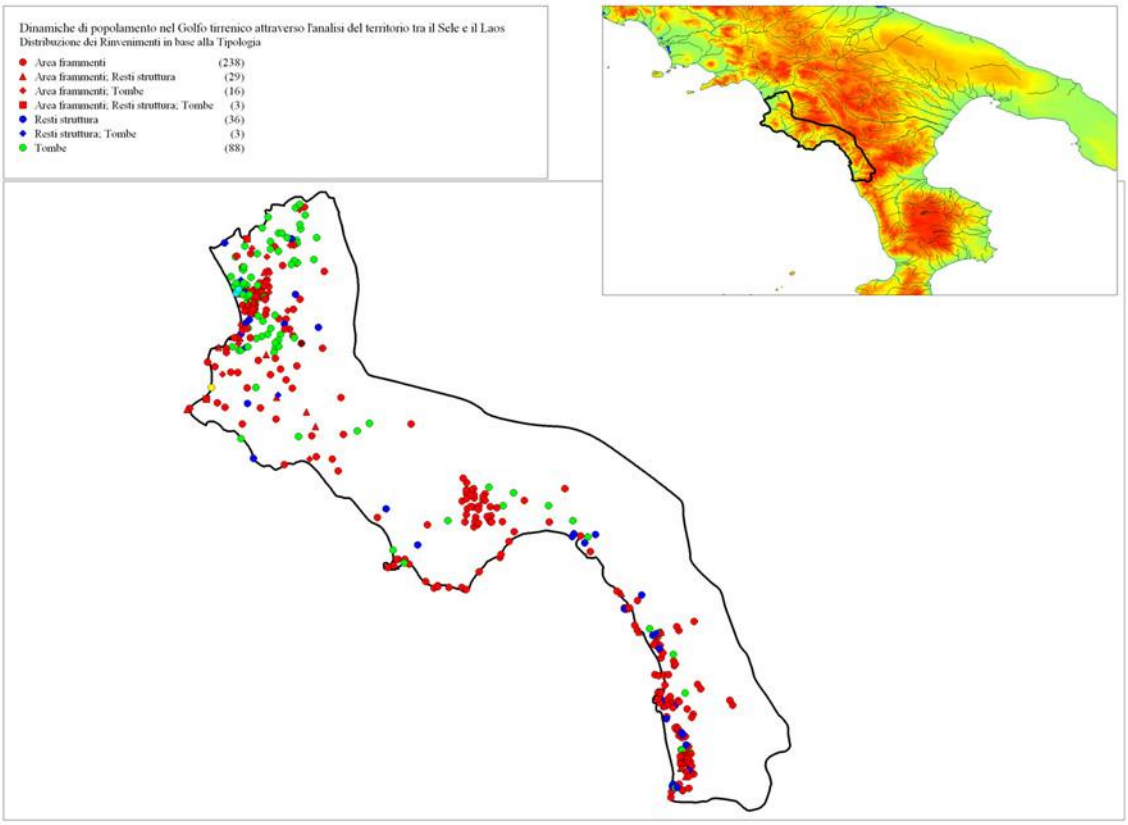

Fig. 4 – Distribution of archaeological evidences classified by type.

These maps are bidimensional. It does not mean that the space is bidimensional. It means that the maps have just two dimensions: one for space and one for time. The maps are telling us that there are evidences in a punctual location and in a given period, solely a wide range of time. In other words, the space is just a background, the time an attribute (Fig. 5).

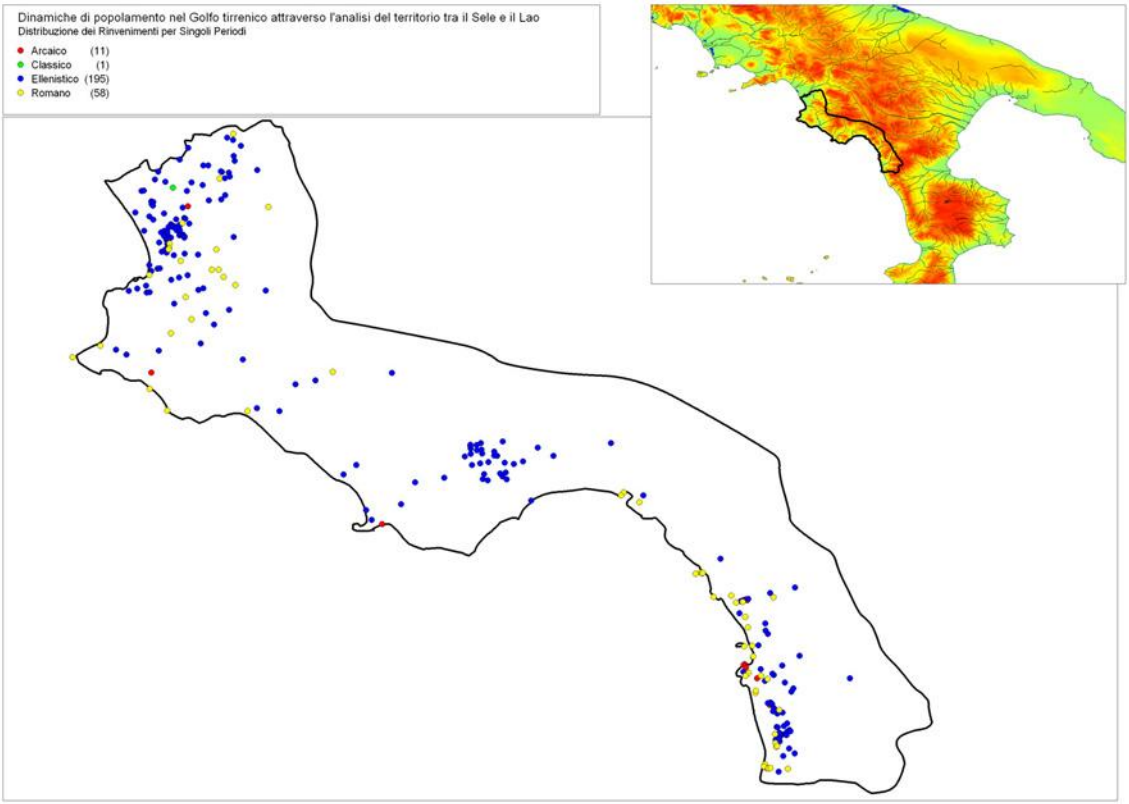

Fig. 5 – Distribution of archaeological evidences classified by chronology.

The presentation of the data leaves no room for consideration about the nature of the data. The general approach is the global census of the sources. The purpose of the catalogue has more importance than the analysis. In the absence of a unitary spatial connection plan and in the absence of a chronological mutliscalar grid on which projecting documents according to their intrinsic value and according to the fluctuations coming from the uncertainties of dating, bibliographical (or traditional) sources are isolated points in space; the results create a generalized and locked composition, even if valid for a long period synthesis, not essential for the representation of evolutionary processes, articulated in time.

In short, the character of the traditional approaches to the study of the territories can be summarized with the following scheme.

Main features of the traditional approaches:

► Generalization of the relationship between environmental and physical characteristics of the area and archaeological sources

Adoption of small-scale geo-environmental studies and general

Suggestion:

– Adoption of detailed studies performed with current techniques of investigation

- Lack of quantification
  - Absence of a definition of site as a place of ancient human activities
  - Variety of methods used in data collection leading to difficulty in comparing results
    - Suggestion:
    - – Integration of data from different document management systems, each defined by its own epistemological
    - – Work in warehouses and archives
    - – Acquisition of recent detailed studies
    - – Execution of targeted investigations for certain areas
- Generalization of the chronology
  - Presetting of periodization in the definition of long-term dynamics
  - Modelling patterns of population defined on the basis of literary sources and historiographical studies
    - Suggestion:
    - – Redefining chronology and dating. Using different assignments chronograph.
    - – Implementation of probabilistic and statistical methods
- General uncertainty in the definition of the spaces exploited in ancient times
  - No systematic excavations and exhaustive researches
    - Suggestion:
    - – New scan areas of discovery
    - – Compensation between data consolidated and research in progress
- Proliferation of vocabularies and terminologies that identify the use destination and interpretation of archaeological sources
  - Difficulty in comparing the findings and find difficulty in connection and relationship between them
    - Suggestion:
    - – Simplification of language concerning the real nature of the recovery

The attempt to look for a different approach to improve data is based on three jobs: Update the catalogue of archaeological finds by consulting all the available bibliography and each archive; field survey in the territories of Laos and Poseidonia with actual *standards* and techniques; creation of tools for recording, management and evaluation of bibliographic and archival data and field surveys. At this stage a new database was built, in order to allow a comparison of the traditional type of data and data updated to the current methods of investigation.

An analytical tool

On closer inspection, there are no traditional sets of data. There are sets from the tradition. What characterizes them is the method of collection and their destination. For this reason, it is possible to consider that they are always contextual, at a period, at an approach, at a purpose. If this assumption has a value, then a revision of the data must first analyze the context in which they were produced.

From a technical point of view, the instrument is simple. It is a db connected to a gis. Its logic is more complex, since the aim is to integrate documents apparently not commensurate, with the risk of solving the

integration into a mere juxtaposition. Its structure follows the singular criteria of the data production. The aim is to recreate the context (Fig. 6).

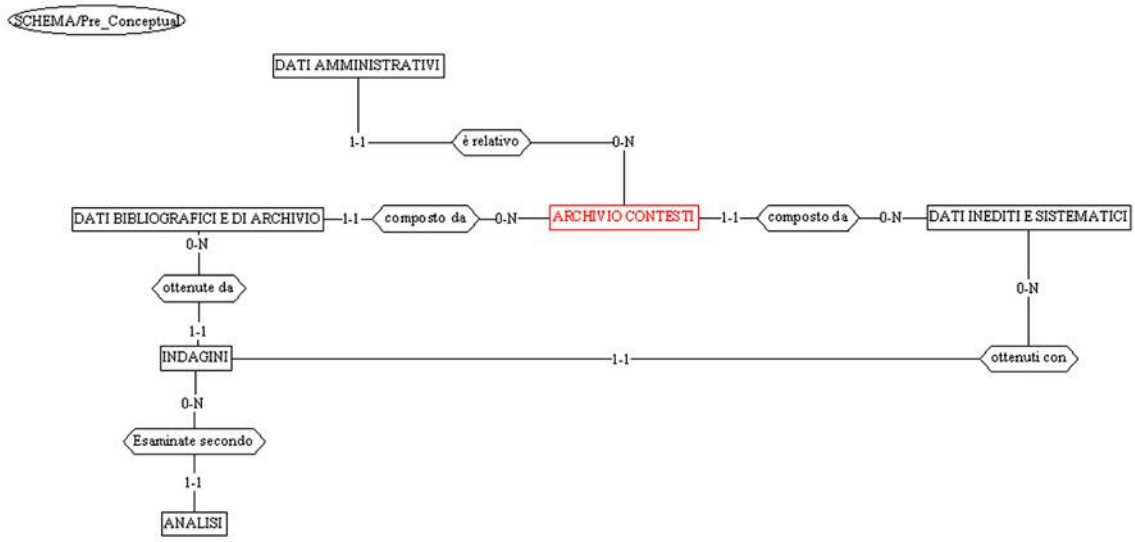

Fig. 6 – Conceptual scheme of the recording system.

Given that the context is the result of a tendency of research. It is not given once and forever. At the same time it is a place. And it is 'heterogeneous. It is the complex of meanings that have been sought and assigned.

The physical development of the system follows this approach, according to a scheme that finalizes the recording of any information to the definition of the level of systematicity of the context.

In short, every field of every table in the database is the result of an action of decomposition and deconstruction of an archaeological source (bibliographic or archival, published or not) in a system (filter) created for subsequent analytical levels. This logic starts from the awareness that once defined a space you can define the characteristics of research that have been produced and the results obtained (Fig. 7).

The db is made up of over 100 tables and a 64 input layout, search and visualization. It opens with a layout for the search and selection of groups of records, sorted on the basis of administrative or typological attributes.

The main section is to display the *context* entity with all its attributes, spatial and structural. On the same screen you can read and analyze each source, published and unpublished. Through the navigation buttons you can access the information of the characters of each source: typology, chronology, diagnostic elements, interpretation. From a logical and relational point of view the contexts have a one to many relationship with each sources. The same relationship characterizes the relationship of each source with the *set* of interpretive information. From this screen you enter the second level of analysis, which is for the individual investigations. At the end of the path is the level of quantification and qualification of findings. These modules allow the acquisition of material data, organized for further stages of analysis: *SM* (where the objects are clustered into classes: ceramics, metal, stone, etc.); *TMA* (where the objects are grouped into typological series); *Reperti* (where the finds are considered individually); clay table and table structures.

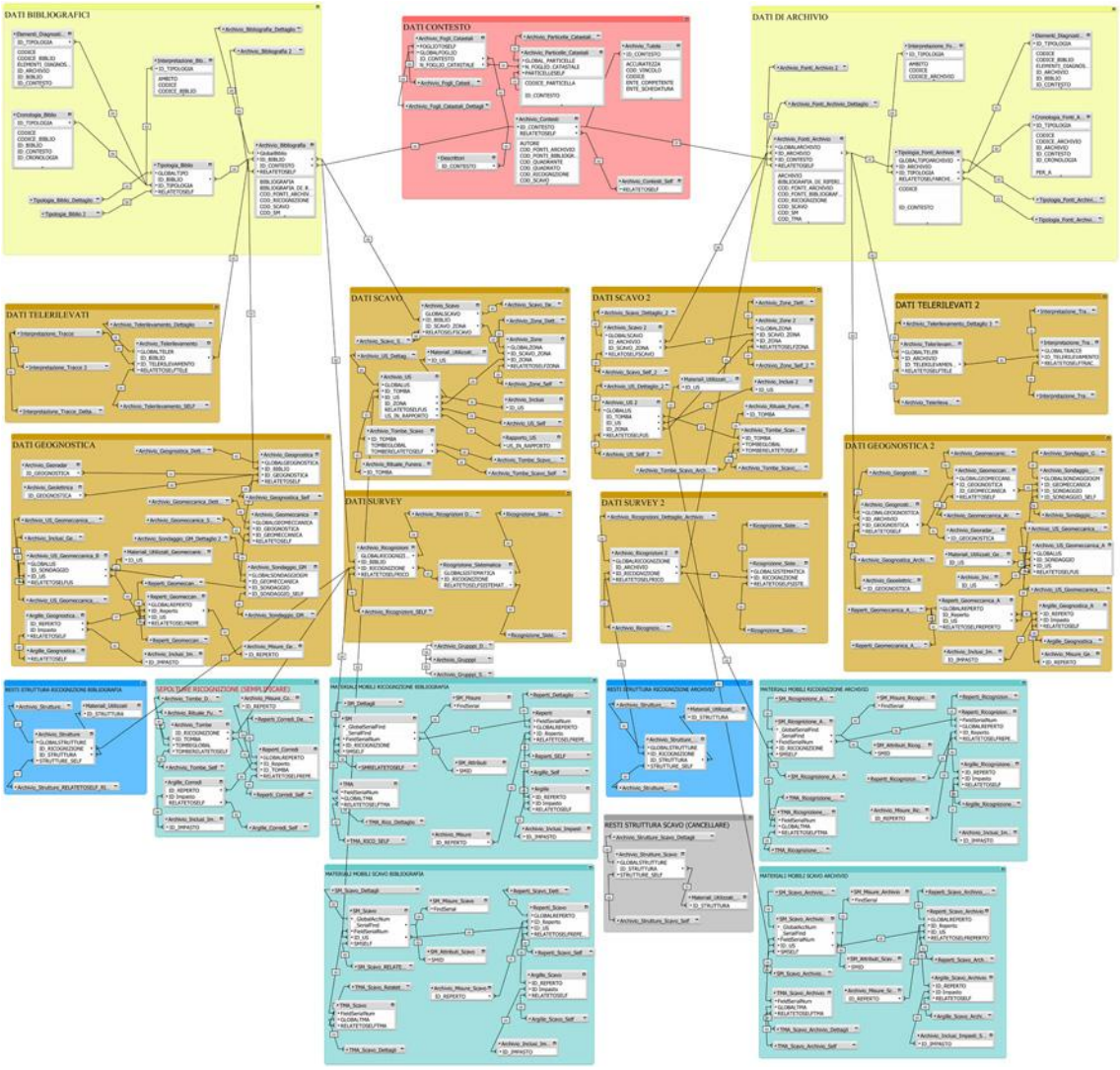

Fig. 7 – Relational scheme of the recording system.

The database considers all the needs of data recording: *excavation* (with the special case of stratigraphic units related to tombs (tombs are a large *set* of documents in the territory of Magna Graecia), in this way you can automatically build a catalogue of burials); *survey* (in this case it took into account the variety of types of surveys, with the proposal of different paths depending on the different degree of systematicity of each exploration: intensive, extensive, unsystematic, intrasite, urban survey, etc.), *remote sensing* (you can enter general information about an investigation of remote sensing and details about the traces connected); *geological investigations* (in this case it appears the archive dedicated to the geomechanical. It consists of information about the campaign, the individual test (standard penetration test) and individual stratigraphic units of each test).

The database is produced, and still is in progress, to accomplish the request of an integrated GIS and multi-platform database-independent. There are two distinct types of data the coordinates and the archaeological information. The coordinates are filled in the GIS and then exported to the database (BOVE et al. 2004). This is possible thanks to an "interchange file". The geographical and archaeological data, related to each element, can be exported again to a GIS and this allows qualitative and quantitative analysis.

Some results

The transition between the definition of a geographical area, archaeological investigations, data analysis and interpretation of the context can not be considered deterministic. It is the result of superposition and comparison.

The expected result is to get a different composition of the archaeological record in a different qualification. The data are in fact cultural entities, characterized by variability, from spatial, temporal and functional standpoints. The change in the levels of approximation and accuracy of each of the three entities will change the cognitive value of the data. Based on these considerations we arrive at the maximum critical point regarding the evaluation of data in relation to what has been modeled in the studies of traditional character. In the two examples i suggest you can appreciate significant differences. The first example concerns the southern portion of the city of Poseidonia (Fig. 8). We can see 4 different types of information: areal forms, result of spatial recomposition of bibliographical and archival sources, a systematic survey plan with the quantitative distribution of finds; punctual information, relating to traditional mapping; the urban cemeteries, drawn to realistic scale.

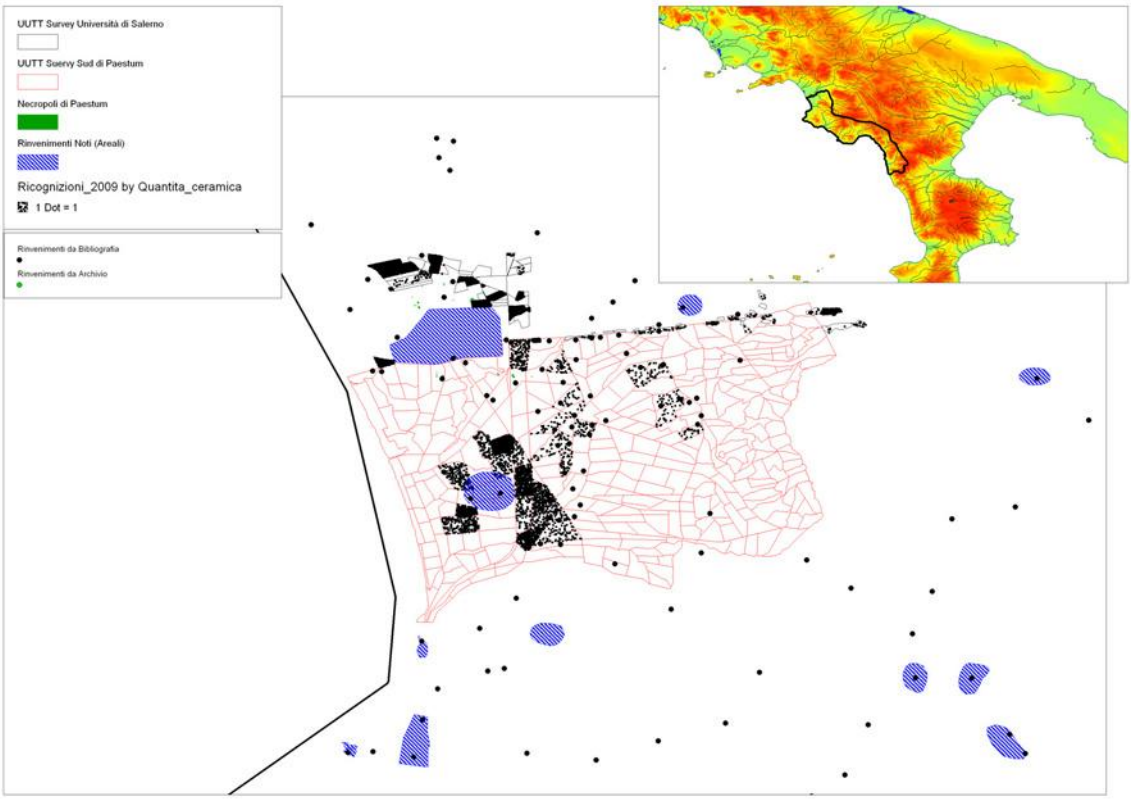

Fig. 8 – Southern area of Poseidonia-Paestum: overlay of different types of archaeological data.

Every place of the space is considered a context. We can see the differences between the traditional distribution (single points) and that contextual, made with various types of forms. In summary, the archaeological evidence is transferred to a general plan for a real relationship. It does not ignore the assessment of the validity of the information, its degree of reliability. Whether or not representative of actual human activity. Space acquires dynamism in the sense that you create a grid that links each location, which

tightens the surface, a vision that exceeds the discretionary distribution of recoveries in which tracks are isolated and separated with the risk of over-or underestimate the data and with them the territory. The space here is more experienced, and exploited than has been interpreted hitherto. According to a traditional view of the southern portion of Paestum, the area is intended for burials and is linked to artisan and merchant functions for the presence of a supposed village, highly centralized. Excluding agricultural activities, which are the main factors of the population expansion in the countryside. These are located in the northern portion of the territory of the colony. The map shows us how this vision should be, renewed or at least, should be limited.

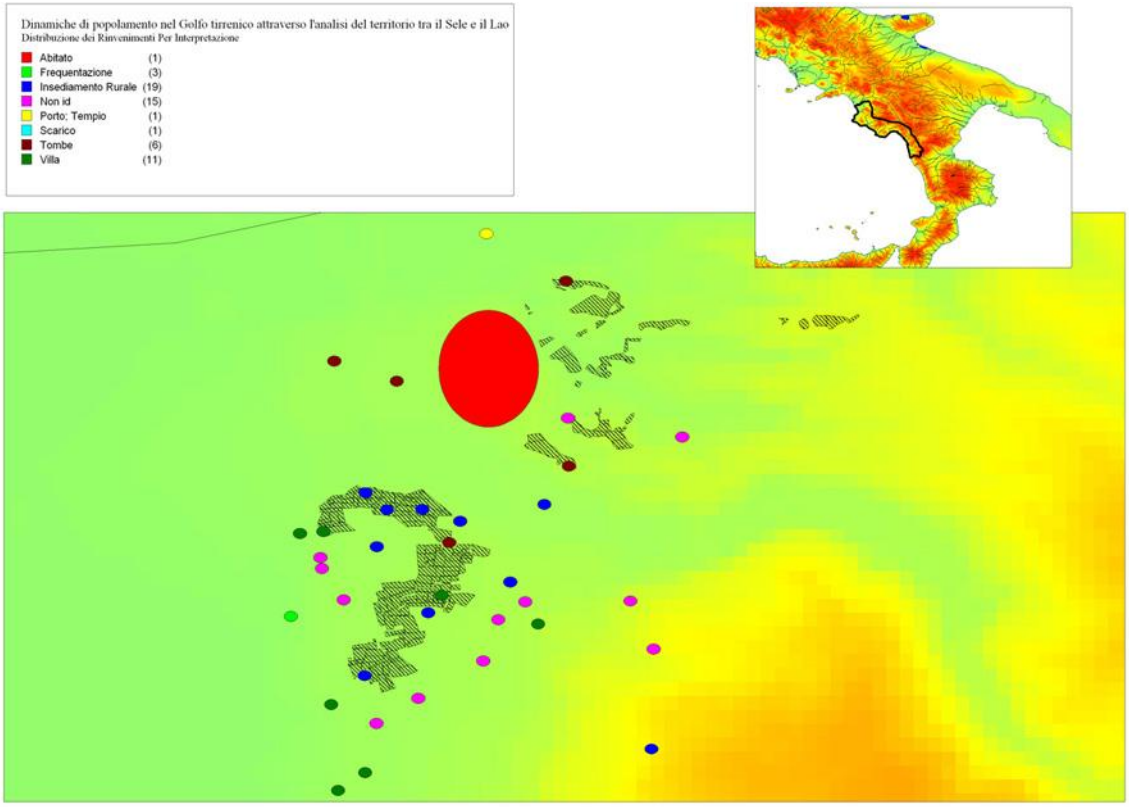

Fig. 9 – Area of the city of Laos: distribution of archaeological data classified by type.

The second example concerns the plain of Laos (Fig. 9). Again we observe the same levels of information. The traditional interpretation shows that the area is densely occupied by hellenistic small agrarian settlements and roman villas. I suppose that this view must be revised, looking for differences in function and chronology rather than supporting a system of simultaneous production activities in the territory.

In this case, we must also consider the chronograph issue. The chronological values are the basis for the evaluation of the occupation of territory. Traditionally, at a given chronological classification of the evidence corresponds to a defined profile of the population. All the evidence is collocated in a portion of time according to a few diagnostic elements (Fig. 10).

A sherds area with hundreds of elements, for istance, is the source for the existence of a farm or a villa. So territory appears densily occupied in hellenistic and roman periods. A connection too mechanistic. This is

highlighted by the distribution of levels of approximation of the temporal frequency of each discovery. If we consider the distribution of this allocation, we can establish a new process of interpretation.

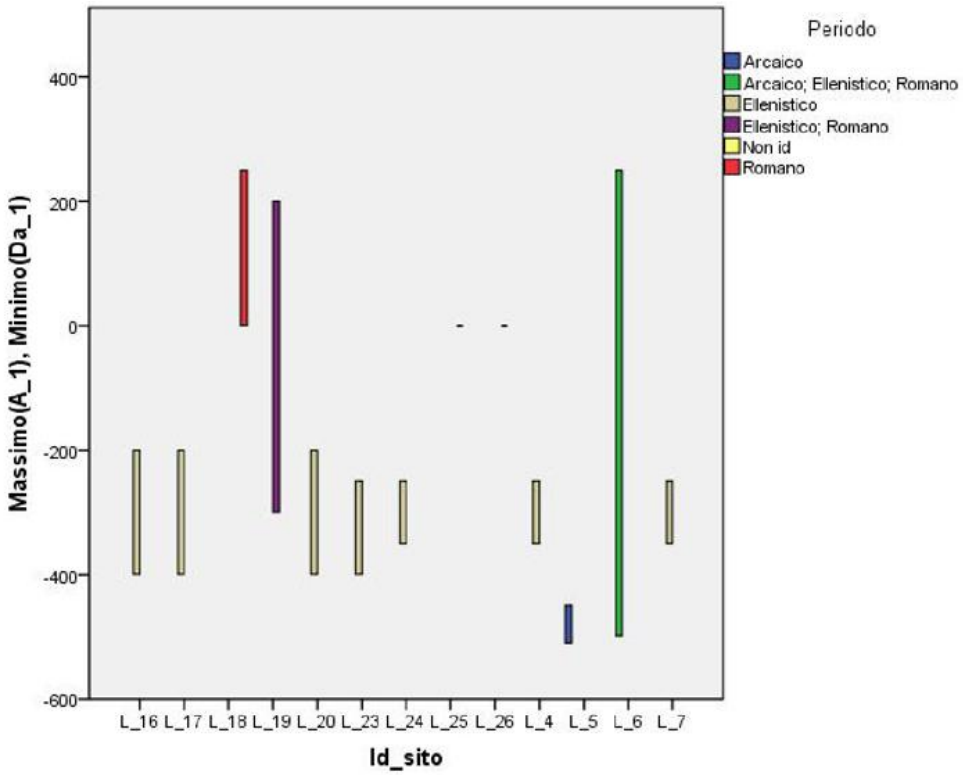

Fig. 10 – Area of the city of Laos: distribution of chronologies according to the conventional scheme of traditional researches.

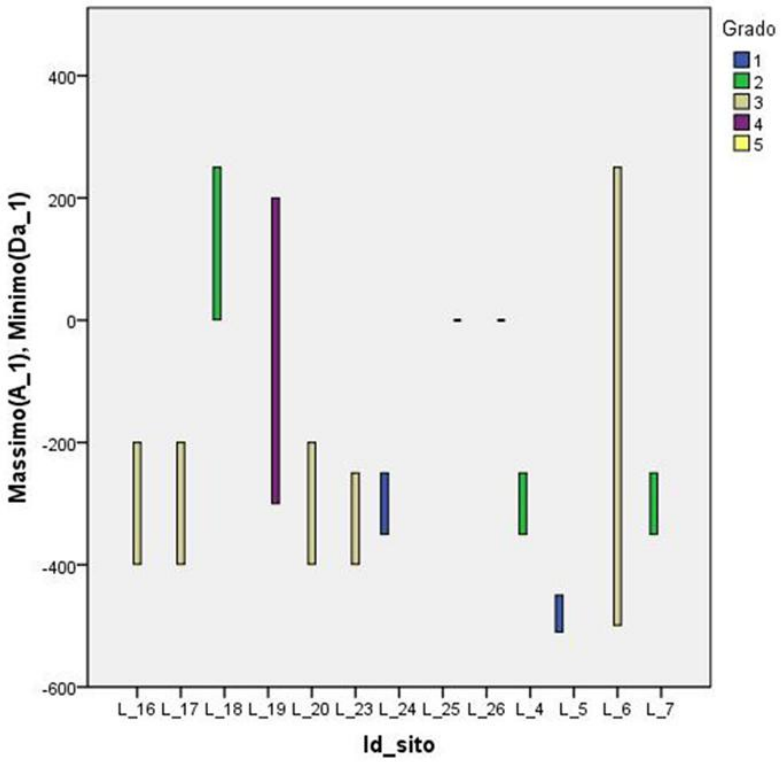

Fig. 11 – Area of the city of Laos: classification of levels of reliability of the chronologies.

I classified all the temporal attributions in 5 levels (SANTORIELLO and SCELZA 2008; SCELZA 2009): the smaller is the value, the less reliable is the attribution of the chronology (Fig. 11). In other words, we have to take into account small-scale archaeological realities, consisting of sherds areas, free of significant reasons of differentiation: the very wide range is in fact the outcome of a process of periodization that justify continuous archaeological entities. It means that it is not really true that territory has long terms entities and they probably dont live together. The second step is to place these new chronological ranges on the real time scale. It appears a new configuration, in which the spatial distribution of different entities composes a new anthropic landscape (Fig. 12).

This allow us to hypothesize that the area in question has not been densely exploited by a high number of distinct production facilities in the same period. In this case, the proposal to dilute the evidence over time is the basis for understanding the different meanings of land use and of territorial organization.

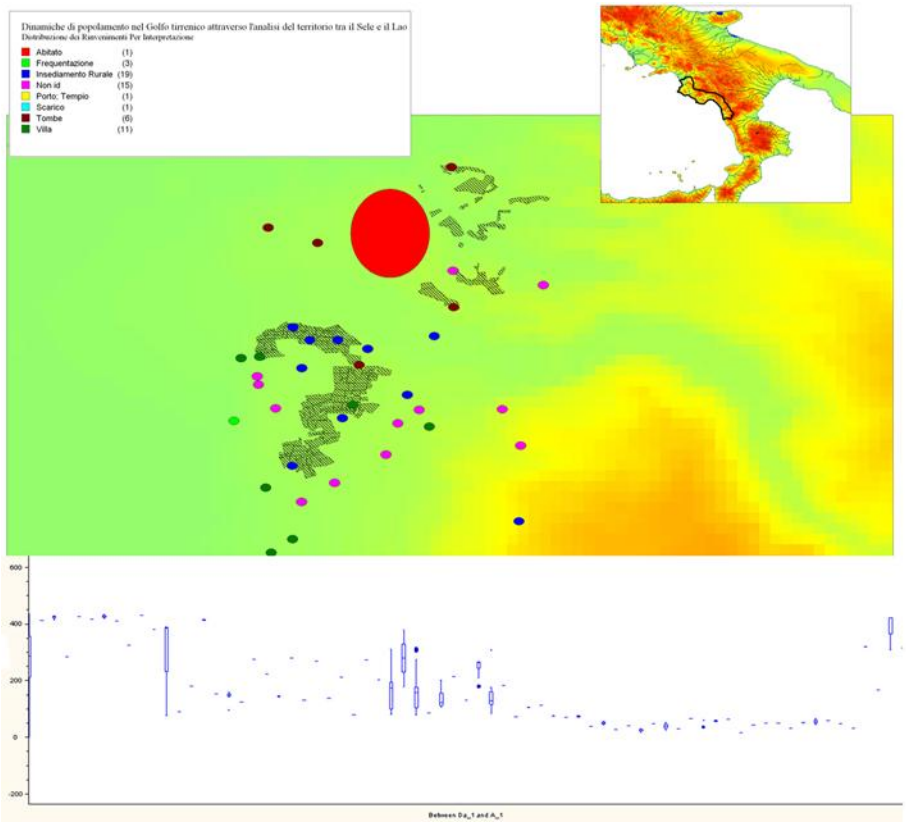

Fig. 12 – Area of the city of Laos: new modulation of the chronologies of archaeological data according to the degree of reliability and amplitude of dating of all findings.

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Consolidated Visualization of Enormous 3D Scan Point Clouds with Scanopy

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Abstract: Terrestrial laser scanners are used at many excavations for documentation and inventory taking. For the documentation of the excavation Amphitheatre 1 in Bad Deutsch-Altenburg, Austria, the terrestrial laser scanner Riegl LMS Z420i was used. Overall, the entire excavation was covered by about 200 positions. With each scan position the amount of data recorded increases and this leads to performance problems in the visualization of the data. Due to the enormous number of points a consolidated representation of the entire point cloud is not possible with conventional software. The software Scanopy was developed for presenting and editing huge amounts of point data. Furthermore, it is possible to load polygonal models and display them together with point clouds in one scene. This allows an exact documentation of large archaeological excavation sites. Another application is the visualization of polygonal models of different excavation levels. The simplest visualization of point clouds on screen is a representation of the points as square rectangles. This, however, creates geometric inaccuracies, and colored point clouds are presented with sudden color changes. When the points are displayed by using semi-transparent circles the 3D points can be blended and lead to a more homogenous visual representation of the scanned objects. Thus the visual impression of the point cloud will be improved considerably. The developed software is demonstrated on the excavation mentioned above.

Keywords: point-based rendering, out-of-core processing, range scanning, virtual reconstruction.

Introduction

The roman amphitheater in Bad Deutsch Altenburg/Austria is one of the most attracting monuments of the archaeological park Carnuntum. Therefore the provincial government of Lower Austria carried out several 3D laserscanning data acquisitions to document this ancient site. Within a period between 2007 and 2010 about 200 scan positions have been placed to acquire the whole historical building structure as well as to document the ongoing excavation process. To acquire the data a Riegl LMS 420i Laserscanner with a Nikon D 70 Digital Camera mounted on the Scanner has been used. The whole data has been georeferenced in the national coordinate system by using tie points for a coarse registration and identical patches for the multi-station adjustment. An overall accuracy of 1–2 cm for each scan position has been accomplished.
For visualizing the point model of the above mentioned excavation we are using the point cloud viewer/editor Scanopy (SCHEIBLAUER and WIMMER 2011). With Scanopy it is possible to view huge point clouds that do not fit completely into the main memory of the computer, and also to edit them. Furthermore, polygonal models with detailed high-quality textures can be rendered in a combined viewer (MAYER et al. 2011),

allowing to show the whole area of an excavation site by a point-based model, and interesting details, e.g., walls with paintings, by textured polygon-based models. In the following we will describe a rendering method for point-based models, which allows showing details of the scanned objects even when using splats larger than 1 pixel for the points.

Point Cloud Rendering

The visualization of huge point clouds coming from laser scans is a challenging problem due to several issues. First the amount of data produced by the laser scanner has to be handled. The latest generation of laser scanners can generate a billion (10^9) points with one single scan (RIEGL 2012). Only storing the positions of the scanned points will need 12GB of memory (assuming 3 “float” data type values per point for the position, which results in 3*4 bytes per point position), making direct visualization of this data infeasible for current generation computer hardware. Second, if colored points are used, the colors of the points have to be harmonized. The colors are derived from photographs, which were taken at the scan positions during the scan process. The lighting conditions often change when the scanner is moved to a new scan position, be it due to artificial lighting or due to changing position of the sun when scanning outdoors, or other reasons. When points from two different scan positions, which sample the same area, are colored by different photographs, then neighboring points in the combined point cloud will exhibit different colorizations for the scanned area. These color differences can become quite noticeable for a user. And third, the density of the points in a point cloud that is combined from several scan positions will vary locally. This creates unwanted holes in a visualization of the point cloud. To alleviate the problem a varying point size for rendering can be used, so that areas sampled at different densities often appear with closed surfaces regardless.

While we already proposed methods for two of the before mentioned issues, i.e., how to handle the huge amount of data and how to account for the local varying point density during rendering (SCHEIBLAUER and WIMMER 2011), the issue of the noisy colors in point clouds remains. In the following we will first describe how point cloud rendering can be done with simple OpenGL splats, and then we will describe rendering with Gaussian splats, a method which alleviates the color noise issue, and which also allows showing details of the scanned objects when using splats larger than 1 pixel for a point. Note that we use unprocessed point clouds, i.e., no pre-processing is done on the point clouds except for colorization. Therefore the point clouds we use for visualization will exhibit noise in position of the point samples as well. Furthermore we make no assumptions about the uniformity of the sampling, i.e., the point clouds can have widely varying local sampling densities. Executing no pre-processing enables us to use the original point data coming from the laser scanner.

Rendering with Box Splats

We are using an out-of-core approach for rendering a huge point cloud (SCHEIBLAUER and WIMMER 2011). The points are sorted into an octree-based data structure, and for the current viewpoint the most important points are chosen for rendering. The importance is a function that can be defined by the user, for example points projected to the center of the screen shall be preferred. Points which are currently not

available for rendering are streamed in from the disk to the memory. The octree-based data structure also allows for level-of-detail (LOD) rendering, meaning that only few points will be rendered when the user's viewpoint is far away from the point model, and more points will be rendered when it is close to the model. We also incorporate a point size heuristics to account for differences in the local density of the point cloud (SCHEIBLAUER and WIMMER 2011). The point size heuristics adapts the rendered point size (i.e., the splat size of the projected points on screen) for the points of each octree node, i.e., all points of one octree node have the same point size, but the point size is different for each octree node. The point size heuristics is dependent on the number of points in an octree node and on the depth of an octree node in the hierarchy. The denser the point cloud and the deeper down the hierarchy, the smaller the points will be rendered. This also means that points which have neighbors further away will be rendered larger, possibly closing holes in the point model. Since it is a heuristics it does not work for all areas of a point model.

Fig 1 – The image shows a detail of the point model of the Amphitheater 1 in Bad Deutsch-Altenburg. The points are rendered with one color per splat. The single stones of the wall are not clearly visible due to color noise and overlapping splats.

After choosing the points and calculating the point sizes with the point size heuristics (these two steps are done in every rendered frame), the points are then projected to screen and rendered as simple screen-aligned OpenGL splats. These splats are drawn as square rectangles. When using color for the points, this rendering method will lead to color noise (a term which refers to the abrupt changes in color for neighboring splats). The reason for the color noise is that the splats which are used for rendering might be overlapping in screen space. Rendering with box splats and one color per splat results in images like Fig. 1. As can be seen, the whole point model exhibits a lot of color noise. The point size heuristics fills most holes in the point model, only at the staircase in the center of the image holes in the model become visible. Improving the quality of the rendered point cloud would mean to increase the sampling of the geometry.

Since the point samples are given we cannot increase the sampling. Therefore we implemented a rendering method based on signal reconstruction theory, which is described in the next chapter.

Rendering with Gaußian Splats

Instead of rendering each splat only with its color, the rendering technique termed Gaußian splats blends the contribution of neighboring splats overlapping in screen-space. This way a reconstruction of the underlying signal, which consists of the colored point samples, can be performed at the pixels in screen space.

Texture Mapping and Resampling Framework

Gaußian splats are based on the work by ZWICKER et al. (2001), who introduced the elliptical weighted average (EWA) texture mapping and resampling framework for point-based rendering. With this framework it is possible to apply textures to irregularly sampled point-based models in highest quality. We adapt the framework for application on noisy point clouds with widely varying sampling densities.

The EWA framework is based on the idea that point-based models can be interpreted as a discretized function of the surface geometry. For colored point clouds also the texture of the surface geometry is therefore discretized. The reconstruction of the texture for every part of the surface geometry makes it necessary to first reconstruct the texture signal (i.e., the intensity in each color channel: red, green, blue) as a continuous signal, then warp the continuous signal from object space to screen space, band limit the warped signal, and finally sample the band limited signal for display on screen (ZWICKER et al. 2001). The third step, band limiting the warped signal, is necessary to avoid aliasing artifacts in screen space when projected splats become smaller than a pixel.

The original point-based EWA framework was slightly simplified to make it amenable for use on today’s graphics processing units (GPUs). The complete evaluation of the EWA framework is compute intensive, and so some approximations were derived which allow using the EWA framework also for fast rendering of point clouds (BOTSCH et al. 2005). For unprocessed point clouds, as the ones we are using, we are making further simplifications. As we do not have a normal per point, shading and orientation of the splats are neglected. Also the blending depth, as described later, is set to a constant user-defined value throughout the point cloud for all points. In uniformly sampled point clouds the blending depth is usually set to the average distance of points or to the radius of a single splat, but in noisy point clouds both measures are unreliable estimates, therefore the blending depth can be set by the user.

Splat Rasterization

In our simplified version of the EWA framework the splats of the points are drawn as screen aligned square rectangles, which are then shaped according to radial basis functions centered at the projected point positions in screen space, i.e., they appear as circular disks. The size of the square rectangles is calculated by the point size heuristics. Since we use unprocessed point clouds, we do not calculate an exact splat radius (so that neighboring splats are just slightly overlapping while still creating a closed surface) for each point, but use the point size heuristics instead.

Implementation for use on Graphics Hardware

Rendering a point cloud with the Gaußian splats is done in three steps, which are executed in every rendered frame. First all points that are available in the view frustum are projected to screen space and the so created point splats are used to fill the depth buffer of the viewport. The depth buffer is used as input to the next step as depth image. Note that in the first step no color information is used. In the second step, all points are projected to screen space again, but this time the previously calculated depth image is used to discard points that are invisible. The pixels of the splats produced by these hidden points would be discarded anyway, but the reason why this is important in the second step is, that the information only from really visible points is blended. The blending of the splats is done according to a Gaußian weighing function (Fig. 2). There pixels which are close to the projected point position get the highest weight for the point's color. When blending two splats, the weights for the colors from the two splats are used to determine the contributions of the colors for the resulting pixel. In the third step the accumulated color information for each pixel is normalized, since usually the contributions of weights do not sum up to one for each pixel. This would lead to artifacts in the blended colors.

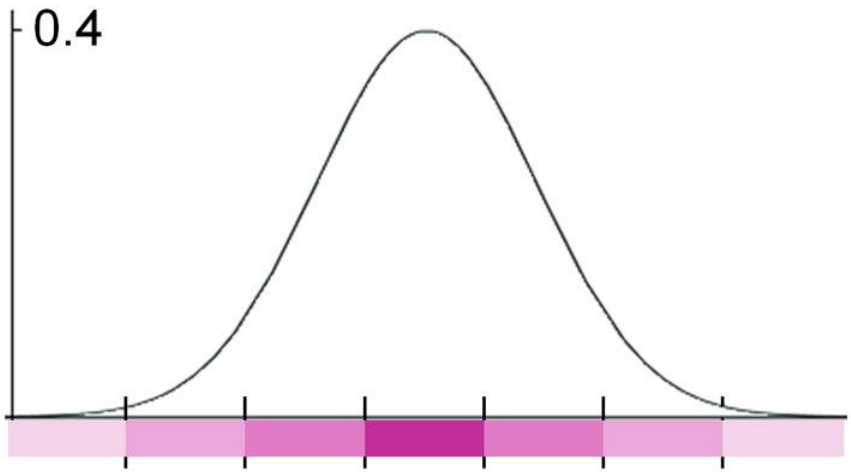

Fig 2 – A Gaußian weighting function. The color of a point projected onto the center pixel is weighted very high at the center pixel but weighted lower at the neighboring pixels, according to the Gaußian distribution.

Results

An example for a point cloud rendered with Gaußian splats can be seen in Fig. 3. The details of the stone wall are much more visible compared to the simple rendering in Fig. 1, and the color noise is greatly reduced. Some noise is still visible, which has two sources. One source is outliers, which could be removed by manually cleaning the point cloud. The second source is points which are colored by photographs with very diverging lighting compared to their neighboring points, so that blending the splats cannot compensate for the differences in the color.

Conclusion

We have presented a rendering method for huge unprocessed point clouds, which allows showing details of the scanned objects even when using splats that are larger than 1 pixel per point. This is achieved by a

blending algorithm, which is based on the point-based EWA framework. We showed the rendering algorithm on a point cloud of the Roman amphitheater in Bad Deutsch Altenburg/Austria, which consists of 105 million points. We hope this rendering method will increase the usability of visualizations of raw unprocessed point scans for everyday users, like archaeologists.

Fig 3 – The image shows a detail of the point model of the Amphitheater 1 in Bad Deutsch-Altenburg. It is the same area as in Fig. 1. The points are rendered with Gaußian splats. The single stones of the wall are clearly visible due to reduced color noise and blending overlapping splats.

Acknowledgements

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Integration of different geodetic measurement techniques for renovation and restoration of cultural heritage

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Abstract: Detailed documentation of cultural heritage is one of the main tasks that should be performed for the restoration renovation and archival purposes. The documentation procedure often requires integration of different measurement techniques. Employing various measurement techniques simplifies the documentation, however means a lot of work and time.
The north tower of Seddülbahir fortress, which is our case study area settles on a huge area comprising nearly 24.000 m^2 and has a building mass of 4200 m^2. Due to the large area that the fortress covers, it is not practical to measure the whole area using only classical geodetic measurement equipments like theodolite, level etc.
Terrestrial laser scanning technology is a new and quick geodetic data collection technique compared to the classical geodetic measurement techniques. Although the equipment costs are high and the evaluation of the point clouds requires special knowledge it shortens the time necessary for measurements.
In this paper the geodetic measurement techniques employed for the documentation of Seddülbahir fortress will be explained in detail.

Keywords: Cultural heritage, Terrestrial Laser scanning, Documentation.

Introduction

The fortress of Seddülbahir is situated in the small village of Seddülbahir overlooking both the Aegean Sea and the entrance to the Dardanelles. It was built on the European side, across from the Kumkale Fortress, by Hatice Turhan Sultan, the mother of the Ottoman Sultan, Mehmet IV. The fortress was endowed with a mosque, a double and single hammam, housing for soldiers serving in the fortress and additional shops and markets.
Initially the fortress was constructed as part of the Ottoman defense against Venetian naval incursions into the Dardanelles during the long war over Crete. Since that time it has served the Ottoman and later Turkish defense against a variety of enemies who have coveted either the strategic outlet to the Aegean or a convenient sea access to the Bosphorus and the capital of Istanbul. Seddülbahir Fortress was instrumental in the Gallipoli campaign of World War I and severely damaged by artillery fire. After World War I and the withdrawal of British troops from the Gallipoli region, fortress was returned to the Ottoman government. Until the spring of 1997 Seddülbahir Fortress was maintained as a Turkish naval outpost.
The fortress of Seddülbahir, on the European side of the straits is located near the mythical site of the tomb of Protosileus, the first of Agamemnon's soldiers to have fallen in the early days of the Trojan War. Indicated as Cape Hellas and Ertugrul Bay in the military maps of World War I, Seddülbahir is the fortress where both the French and the British staged major invasions during the Gallipoli Campaign and where today, the main

memorial to the British, Australian and New Zealand forces commemorates soldiers lost during the campaign (Fig. 1).

Fig. 2 – General view from Seddülbahir Fortress.

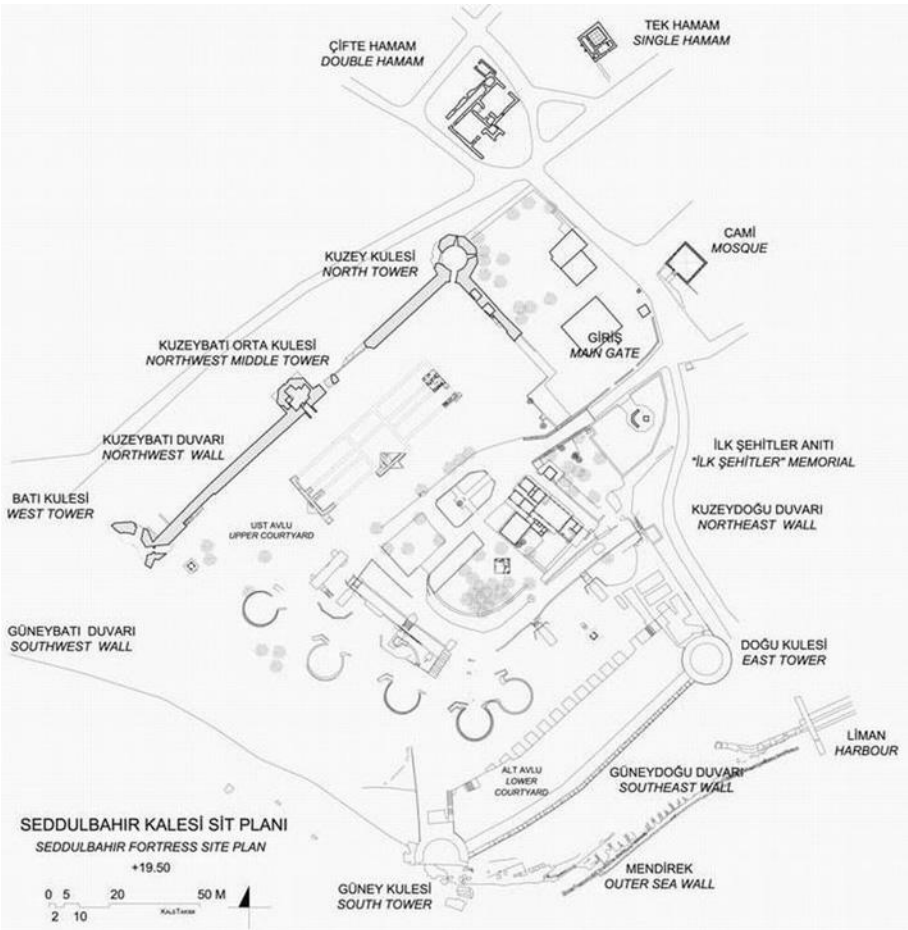

Fig. 2 – Seddülbahir Fortress Site Plan.

The aim of the architectural/Geodetic survey and historic documentation project of Seddülbahir Fortress is twofold: first to document the existing remains of the fortress by generating the geodesic maps and architectural drawings of the structures on the site; second to bring together a vast array of data such as repair records (tamirat defterleri) from the Ottoman archives, European and Ottoman historical chronicles, drawings, engravings and archival photographs from various libraries' collections in order to assess the development of the structure and propose a plan for the preservation and restoration of the fortresses and adjoining structures. This paper will concentrate on the geodetic surveys carried out to obtain accurate documentation (topographical and architectural) of the Seddülbahir Fortress (Fig. 2).

Survey Methods

As first step of the surveying, surveyed area was visited to determine what would be measured and which survey techniques would be used, depending on the topography and the structures of the fortresses before beginning geodetic measurements of both fortresses. Many photographs were taken and digital images recorded during these surveying trips. Based on these investigations we determined out surveying plans, methods and the equipment to be used.

GPS and Conventional Measurement Techniques

The surveying work that has been done in the project has been conducted with state of the art surveying instruments, such as GPS (Global Positioning System) receivers, and total stations capable of measuring without reflectors (Fig. 3). Data collection in the field was done using several different GPS techniques, including Static, Kinematic, and Real-Time Kinematic GPS as well as conventional techniques. By employing the most recent GPS technology and conventional measuring techniques, the degree of accuracy in our measurements for the fortress has been significantly increased.

Fig. 3 – GPS and Terrestrial Measurement Techniques.

6 main control points in Seddülbahir were positioned with the GPS (Global Positioning System) technique. The positions of the main control points were determined using GPS static survey and were applied at two hour interval. After processing these sets of data WGS84 (World Geodetic System) coordinates of the main

control points were obtained. The networks for Seddülbahir fortress connected Turkish National Fundamental Network (TUTGA) by means of a TUTGA point with GPS survey with a 2-hour period. The datum of TUTGA is International Terrestrial Reference Frame-Epoch1996 (ITRF96).
Further, terrestrial laser scanning work has been conducted at Seddülbahir to collect additional information about the structures comprising the fortifications and to examine the various degrees of accuracy between measurements of buildings generated using laser scanning techniques and those generated by conventional methods.
Preliminary sketches of the entire fortress complex were made. All structures were photographed using conventional photographic equipments as well as digital cameras. Mortar, metal, stone plaster and limited wood samples were taken from various structures. All samples were inspected, recorded and released for analysis by the director of the Archaeology Museum in Çanakkale.

Terrestrial Laser Scanning

A 3D laser scanner is a device that analyzes a real world object or environment to collect data on its shape and possibly color. The collected data can then be used to construct digital, 3D models that are used in a wide variety of applications.
3D laser scanners record the 3D coordinates of numerous points on the surface of an object. Thousands of points are recorded per second, at milimetric/centimetric grid intervals, across a scanned object to build up a dence 3D point cloud representation of the object containing typically millions of points and requiring specialist software to process. The 3D points are in a common coordinated system that represents the spatial distribution of an object or site. The combination of digital photo modeling and laser scanning can enhance the point cloud data, allowing for the recognition of better definition in the texture and geometry of the scanned objects.
The purpose of a 3D scanner is usually to create a point cloud of geometric samples on the surface of the object. These points can then be used to extrapolate the shape of the object (a process called reconstruction). If color information is collected at each point, then the colors on the surface of the object can also be determined.
Laser scanning, in combination with other digital documentation techniques and traditional survey, provides an extremely useful way to document the spatial characteristics of cultural heritage sites. This spatial information forms not only an accurate record of these rapidly deteriorating sites, which can be saved for posterity, but also provides a comprehensive base dataset by which site managers, archaeologists, and conservators can monitor sites and perform necessary restoration work to ensure their physical integrity.
The entire site (facades and interior walls) was scanned at ±5mm accuracy using a Leica HDS 3000 laser scanner accompanied by a Leica TCR407 Power reflectorless total-station.
HDS3000 has a high accuracy (6mm at 50m) with a maximum 360° horizontal field-of-view and an equally impressive maximum 270° vertical field-of-view (Fig. 4).
The point cloud of the entire site consists of 350 million points. Leica Cyclone software together with Cloudworx has been used for the registration and evaluation procedures of the point clouds (Fig. 5).

Fig. 4 – Leica HDS 3000 Laser Scanner.

Fig. 5– Point Cloud of the Entire Fortress.

Conclusion

Architectural drawings of all structures at Seddulbahir were made according to the precise geodetic measurements procured; this data, along with the positional, graphic and historical documentation related to the project are all being integrated into a common database that will be used for the project.

A survey and scaled drawings of buildings or components, on a scale of 1:20, was made with a traditional measuring system of the eastern and western facades of the north defense wall. The results obtained are used for preparation of a restoration proposal.

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All technical information is taken from the Seddülbahir Fortress Site Documentation and Restoration Project http://www.geo.itu.edu.tr/kaletakimi.

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Prototype GIS for Analysis and Protection of the Bulgarian Archaeological Heritage – ArchGIS

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Abstract: The paper describes an innovative approach to the process of creating a novel GIS for analyses and protection of archaeological heritage of Bulgaria. Firstly, it describes in brief the appearance and evolution of the electronic database for registration and documentation of archaeological sites and monuments known as 'Archaeological Map of Bulgaria' (AMB). Secondly, it gives details about the existing legal framework under which the novel information system and the methods for fieldwork have to be conducted. The imposed by it technical requirements and public obligations entail development of an innovative analytical technique for assessment of the threats of destruction of archaeological heritage. In order to meet these high expectations we suggest a Bayesian statistical approach that incorporates the spatial results obtained from terrain surveys and high-precision registration and documentation techniques into one process of generating key information about the existing threats of destruction of archeological sites in a given region. This procedure is synchronized with the novel methods for fieldwork which are also described briefly. Last but not least the basic functionality and characteristics of the GIS-based Information System are described, including its logic and mode of operation.

Keywords: Archaeological map of Bulgaria, GIS, Bayesian probability intervals, field survey, analyses and protection of archaeological heritage.

Introduction

In Bulgaria the only functioning information system dedicated to protection of Archaeological Heritage is the Archaeological Map of Bulgaria (AMB). It was created in 1990 and currently holds information about more than 16 000 archaeological sites collected from all over the country. For the time period of its existence it played a crucial role both for protection of the cultural heritage of Bulgaria and as a basic tool for proper scientific research. In the present days the AMB database takes the role of a legal institution that operates as a basic reference account regarding the process of protection of Archaeological Heritage. The references made in the AMB are used as legal argumentation for allowing or stopping investments in particular areas. Most of them are required by judicial authorities and police investigations connected to destruction of archaeological sites and monuments. Additionally, the information of AMB has useful application in Cadastral Agency, the Commission of Land-use, woodland services and in other departments of the local administration. The data coming from AMB are considered as official statement having primary importance in the process of assessment of the impact on archaeological heritage caused by potential investors for development of particular areas and land-use.

Apart from the important public role for protection of archaeological heritage the AMB constitutes a valuable tool for scientific research. It provides spatial information necessary for various scientific studies conducted by the researchers from NIAM-BAS, universities and museums. The information taken from AMB is useful for many publications, articles, master papers and doctorates.

The up-dating of the AMB database is a constant process. Its organizational principles integrate the efforts of practically all archaeologists in Bulgaria. The AMB has a top down hierarchical structure of organization. The highest level consists of a body of national coordinators. At regional level, there are 28 regional coordinators that are responsible for their respective regions. All archaeologists employed in national institutions, universities, and regional and local museums participate in the system. This organization is, however, flexible enough and allows each archaeologist to be able to enter or up-date information about archaeological sites that lie outside his/her own region. Each archaeologist in the quality of a user of the Information System has rights to enter, edit and up-date the information about sites he/she discovered during the field work or by chance. If he/she encounters fresh changes in an already registered site whose rights for editing the data are owned by another colleague through the regional or national coordinators he/she is able to up-date the existing register. The register form of the database is large enough and may contain many additional information including photos, drawings, or additional documents attached. It is obligatory rule that any time a new information enters the register the name of the owner of that register or the archaeologist who up-dated it to be recorded. In this way the track of changes in the state of any site, monument, or potentially interested for archaeology survey unit will be tracked down. In addition an option for visualizing any site or any area from the database through their GPS coordinates on Google Earth exists. Since Google scans periodically Earth’s features every few years and since each entry of data obligatory involves detailed topographic maps the difference accumulated through time with the imagery of Google serves as a time map that traces the changes in the actual state of the archaeological site and the changes in the environment surrounding it (the traces of land-use and new construction works).

The general management of AMB is conducted by National Institute of Archaeology and Museum and by the Ministry of Culture. According to the Cultural Heritage Law archaeologists have the obligation to provide information about newly discovered archaeological sites. This information comes either from systematic archaeological surveys or from construction works and treasure-hunters that unearth archaeological remains and subsequently become registered by archaeologists. The data of the registered archaeological sites and monuments are archived in the created for this purpose electronic information system. The first variant of the system was completed in 1992 and it worked under DOS operation system. In 2000 a new version of the database was made that allowed its use under Windows. The new system was implemented in all the museums of the country and considerably increased the efficiency of registration and management of data. Unfortunately, this system is now outdated and does not meet the increasing requirements for processing information as well as establishing better relations between its users. The lack of the possibility for precise localization with GPS coordinates of archaeological sites and their boundaries requires significant changes in the system. This also poses the necessity of increasing the standards of field surveys for registration of archaeological sites and monuments.

The instruction for the registration of new data into the system, the Intellectual Property Rights, the relations between the different stakeholders that are established as a result of the operation of the AMB as well as the

management of the database are described by the newly accepted law for the Cultural Heritage (published in the State Newspaper from 13. 03. 2009) and its last correction made on15 July 2011, article 155, and the Order of the Ministry of Culture No H-2 from 6 April 2011.

Scientific background for improving precision of registration of archaeological 'events'

In Bulgaria, over the last decade the high-precision recording and documentation of archaeological sites have been introduced (SOBOTKOVA et al. 2010), yet aspirations to precise assessment of the spatial distribution of archaeological sites and to better identification of the existing risks for their destruction have not been developed. There are two main reasons for this situation. Firstly, the focus of research has been put only on the precise recording techniques and the documentation of the spatial distribution of archaeological sites. Secondly, because of the landscape dynamics and the unpredictable (from modern point of view) distribution of past human activities this recording of the spatial distribution is imprecise; each survey polygon or region has an associated estimate of imprecision (its standard deviation). Its value does not depend on the size of the surveyed area but on the landscape qualities valuable for past communities in combination with various post-depositional natural phenomena: erosion, landslide, slope processes, and human impact. In this paper we look at a number of issues that relate to maximizing the information collected through archaeological terrain surveys documented and managed by using GIS.

As a start two practical points have to be noted:

1. The interpretation of records from terrain surveys depends both on the accuracy and on the precision of the results coming from the fieldwork. Accuracy can be affected by three main sources of error:
   a. The quality of archaeologists involved in the terrain survey – their ability to observe the traces left by humans in the past in association with other natural processes such as erosion, traces on the surface of seismic activities, etc.
   b. The ability of archaeologists to recognize properly clusters of shards and artefacts on the surface and their recording.
   c. The quality of documentation of all the available spatial information; not having 'forgotten' or misplaced sites and traces of other natural phenomena.

Precision as measured by the quoted standard deviation and determined for each polygon of terrain surveys is based on the error of occurrence of traces of past human activities (we suppose random nature of the distribution of human activities within a relatively uniform in their geological and geographic features terrain units). All the deviations from the standard (as it is typically the case) suggest human and natural threats for destruction of the traces of human activities from the past.

2. The making of archaeological inferences using a combination of GPS coordinates for recording and GIS geo-database for documentation of terrain surveys is commonly more complex than it appears and consequently it is advantageous to view it in three stages:
   a. Definition of archaeological questions in a quantitative manner, if necessary including development of mathematical models to relate events to one another.
   b. Design of the polygons for the terrain surveys that provide the best information for prediction of the spatial distribution of sites with the required precision.

c. Interpretation of the results of terrain surveys within the context of revealing the potential risks for their destruction.

In this paper we suggest a Bayesian statistical approach that incorporates the spatial results from the terrain surveys and the high-precision documentation techniques into one process of generating key information about the distribution of archaeological sites within a given region and the associated with them risks for their destruction. We aim to aid archaeologists, state and local administrations and other stakeholders in selecting the appropriate terrain units with the most vulnerable to destruction sites and monuments. By illustrating with archaeological examples the process of recording and documentation we show the use of a simple analytical technique that can easily be incorporated in the GIS. The use of the latter for data recording and management is the only way to integrate a wide variety of data with analytical procedures that can provide clear evidence for building risk-avoidance strategies by local and central authorities for preservation of archaeological heritage.

The problem starts with the often posed question by investors about what is the probability of occurrence of traces of past human activities in a given plot of land where they plan to do some construction works. We represent this probability by θ. It is the unknown value that is associated with the summary of the decisions taken by past communities for this plot of land. We may represent it with its mean value $\mu(\theta)$. Due to the past human activities and the post depositional processes the experimentally derived values available for $\mu(\theta)$ are not totally accurate or precise. They provide an observation, χ (a specific numeric value), which is an estimate of $\mu(\theta)$. The actual value of χ is one of many possible values that could have been realized. Each actual measurement will produce a different χ. In statistical terms, χ is a realization of a random variable, the latter conventionally denoted by X. We can express X as:

$$\mathrm{X} = \mu(\theta) + noise$$

where the statistical noise term represents the inherent inaccuracies and imprecision in the measurement process. The noise, or error term, is conventionally assumed to have a normal (Gaussian) distribution, with a mean of zero and a standard deviation represented by σ. The distribution of the random variable is, therefore, normal with mean $\mu(\theta)$ and variance σ^2 which is written as

$$\mathrm{X} \sim N\left(\mu(\theta), \sigma^2\right).$$

Predicting single occurrences of traces of past human occupation

Most archaeologists and other interested parties are tempted to apply extrapolation methods of prediction of occurrences of traces, sites, and monuments despite the existing limitations on the use of predicting models of occurrences of traces of past human activities (WHITLEY 2004). The real problem with this approach lies in the fact that within a given polygon prepared for terrain survey there is no part of it that can be considered ‘typical’. The ‘typical’ traces of settlements and burial grounds do not imply in themselves past human behavior governed by the rule of the nearest neighbor. For example, human activities are often executed in distanced, deserted (from our point of view) areas or attracted by unknown ‘strange attractors’ (ULEBERG 2004). The question is, ‘is an estimated occurrence of a site within a given area a good enough indicator for

prediction of another occurrence of archaeological event in the adjacent to it similar in size area'? Clearly, this is not always the case, and the range of predicted occurrences does not show uniformity within archaeologically meaningful scales in the process of mapping the occurrences on a plot. We need to broaden our estimated predictions to a larger region that consists of several polygons. Each polygon will be divided by a grid of survey areas with approximately equal probabilities of occurrence. Through this operation we can calculate with precision the probability for occurrences of archaeological events within this polygon. In a similar way such probabilities can be estimated for the adjacent polygons and within a small region that bears archaeologically meaningful information (TSONEV 2003). Thus we accumulate knowledge and experience that will help us draw general and particular conclusions about the distribution of the archaeological sites and transfer that knowledge for prediction of site distribution patterns in similar areas in other regions.

Replicate analyses for improving precision

Traditionally, improvement of precision is achieved by obtaining several samples (occurrences in a given polygon for terrain survey) from the same event (the polygon represents archaeologically meaningful area) and averaging them. The average result, $\overline{X}$, has a standard deviation of $\sigma/\sqrt{n}$ when σ is the individual standard deviation common for all the individual survey areas which the chosen polygon has been divided to. Averaging is more complicated if values of the n results are different. This entails weighting each result according to the magnitude of the associated standard deviation.

From these considerations it is important to note that the procedure for outlining a given polygon for terrain survey should comprise relatively uniform distribution of past human activities. In other words approximately n archaeological events should correspond to n equal plots of land within this polygon.

Let us suppose that the probabilities for occurrences of sites in a given polygon range between $\theta_o - l/2$ and $\theta_o + l/2$. Also let us suppose that about n archaeological events were found in n plots of land. Their probabilities of occurrence will vary slightly and can be denoted by θ_1, θ_2, ... θ_n. Without any knowledge regarding the θ_i s we assume that each θ_i is equally likely to have come from any plot with probabilities of occurrence falling in the interval $\theta_o - l/2$ to $\theta_o + l/2$. For each of these events we have a standard deviation σ_i. The frequency of occurrences within a given plot, χ_i, whose probability θ_i falls in the interval $(\theta_0 - l/2, \theta_0 + l/2)$ is proportional to

$$\int_{\theta_0 - l/2}^{\theta_0 + l/2} \frac{1}{\sigma_i} \exp - \frac{(\chi_i - \mu(\theta))^2}{2\sigma_i} d\theta = p(\theta, i)$$

The probability of all the θ_i s falling in the interval $(\theta_0 - l/2, \theta_0 + l/2)$ is proportional to

$$p(\theta_0,1) \times p(\theta_0,2) \times .....p(\theta_0,n) = p(\theta_0)$$

$p(\theta_0)$ is calculated for a range of values of θ_0 and then normalized so that their sum to be 1. In practice, $p(\theta_0, i)$ can be evaluated using numerical integration routines. The definition of l (the length of the precision interval) is not an automatic inference. Each polygon is unique in its own rights and additional information from archaeologists, geologists, and other specialists has to be taken into account for the definition of the precision of the length interval. From formal point of view this is so because the relationship between the mean value of a given plot of land $\mu(\theta)$ and the assigned probability of occurrence θ_i is not linear and remains often unknown or not sufficiently defined. This disadvantage turns into advantage because it leaves specialists with the freedom to integrate the empirical frequencies of occurrence of artefacts on the surface with outside statistical information. This allows them to build serious possibilities for occurrence of archaeological sites in the studied area. The advantage of this ‘moving precision’ for definition of the probabilities of occurrences of archaeological events increases the possibility for comparing past human activities discovered in diverse landscapes.

Methods of fieldwork

The AMB institutionalizes obligatory standards for modern methods of field survey. Each field survey, apart from the study of the available literature for the respective region, has to be supported by primary interdisciplinary analyses of the investigated territory. This includes geology, geomorphology, relief, soils, water sources, presence of ore and mining resources, analyses of satellite and aerial imagery, linguistic and folklore studies, etc. Also, there is an obligatory requirement for technical equipment of the field working teams (mobile GIS devices for recording and documentation). The principle of total survey and registration of every trace of human activity in the chosen area is implied in all surveys with exclusions only possible for high mountainous areas with terrains that are difficult to access. The documentation of the walked through regions has to be made according to the primarily defined polygons. For each newly discovered site a standard registration form will be filled up. For the already registered ones the information will be up-dated. Another important requirement is the necessity for widening the use of interdisciplinary studies that are able to contribute to better understanding of the palaeoenvironment. For this reason it is recommended trial excavations to be carried out in places where the already registered sites seem to yield the most promising results. Thus the limited archaeological excavations will provide more precise data for the type and chronology of the sites. Through these excavations it will be possible to define how far the discovered in the terrain traces of human activities relate to particular features and structures as well as to receive better information about the functions and characteristics of the human occupation activities. The results from the trial excavations will provide new information about the influence of the environment on human habitation and the subsequent natural and anthropogenic effects on sediments, cultural depositions and structures.
In realization of these scientific, legal, and administrative goals the present project unites the efforts and resources of the team of Archaeological Map of Bulgaria from National Institute of Archaeology and Museum – Bulgarian Academy of Sciencies, GIS Cartographic Department of Geographical Faculty of Sofia University “St. Kliment Ochridski”, and Centre for Underwater Archaeology – Sozopol. The defined area for field work is

the well-known 'Valley of the Thracian Kings', the administrative region of the town of Kazanlak, South-central Bulgaria.

The methods for the field survey have to meet the following scientific tasks:

- total survey of the region and precise registration of all archaeological events and the associated with them natural phenomena that pose threats to archaeological heritage;
- up-dating the available information of the database of AMB;
- visits to the known archaeological sites in order to register them with precise localization – GPS coordinates;
- the boundaries of the sites with greater surfaces has to be defined by GPS coordinates;
- up-dating the state of preservation of the sites and monuments registered in the database.
- recommendations for the state of preservation of each registered site and will be made.

GIS for recording and documentation of archaeological sites in Bulgaria

Functional requirements for the future archaeological GIS are as follows:

- Creation of the possibility to include structured information from various, mainly humanitarian sciences, but also data coming from the earth sciences;
- Appropriate management of the stored in this way information by using automatic transfer of specialized knowledge;
- use of technologies that correspond to the International and European standards for geo-information systems and exchange of spatial data, commonly known under the term 'interoperability';
- Ability to do spatial analyses and high quality visualization of geographic data for archaeological sites, along with their natural environment.

Information which will be collected and systematized within the future Geographic Information System can be separated into two subordinated levels (partitions):

- Structured information from previous experience and knowledge of the respective specialists. This partition may be called documental.
- Data which correspond to the respective ontology, relations, attributes and rules for use. This way all these ontological and functional aspects of the system will conceptually define every registered event.

Part of the activities included in the project address the creation of a Geographic Information System (GIS) so that it will have better functionality in Internet: easy access, easy registration of new sites, and easy up-dating of information. An innovative Internet application will allow registration of data from a distance combined with regulated access for the end-users. An electronic form will be developed for these purposes. A new approach for data entry online will be proposed to users. All this will be accomplished through the use of the available ESRI ArcGIS 93 server, available at NIAM-BAS in combination with the use of open source products which will enable publishing data online. Doubtlessly the integration of spatial data into a server based GIS will improve the management of the database of archaeological sites/events and will optimize the time for the retrieval of information. All the necessary information will be available at the NIAM-BAS website (www.niam-bas.com/akb).

Using digital data for modelled territory as an environment will enable each site in the future to be precisely positioned through the use of GPS coordinates along with other sources of information. Using digital data for the geographic environment will allow automatic calculation of various characteristics of each point within the territory where geographic data is collected. The following thematic layers of geographical data will be elaborated for a decided part of the country in order to ensure the linkage of archaeology and their geographical environment:

- Archaeological sites
- Digital elevation model
- Slopes
- Aspects
- Geological composition
- Geomorphology
- Soils
- Land cover
- Contemporary infrastructure
- Other

The authorized internet users will have access to the geographic location and the basic functionality of work with geographic data. The project will build up over the old version of the archaeological map of Bulgaria (AMB). The system will be created as an update of the outdated software from the late 90-s and add new types of information, minimal content management capabilities, standard GIS functionality and architecture especially designed to encompass new features and data. The successor of the AMB is to be designed to support both online and offline deployment over a single code base, including deployment as portable application (on a flash memory stick for example). This will enable it to provide both online access to the full database, and offline usage by field researchers for data entry and limited data inquiries (depending on the amount of data carried). By completing the fully automated synchronization for the offline and the online instances the IS will be able to serve all the needs for data registration and reporting of researchers working in distant regions where access to the online application may be difficult or impossible.

The tight integration of the existing GIS server with side software will enable the online version to be extended to provide additional services such as data creation, automatic deduction of geographically dependent characteristics, and registration of sites with the GIS server and a variety of analytical services over the collected data. The IS will be extended to support content management of additional resources such as images, documents and others (with embedded scanning functionality) and various other types of data.

All these features of the system will allow the end-users to have at their disposition the following basic functionalities:

- Interactive data manipulation and navigation;
- Enabling and disabling of layers;
- Identification of features and their descriptive (attributive) information;
- Spatial and attributive queries;
- Creation of sketches and maps;
- Spatial analyses and modelling.

Conclusion

The current project (2011–2013) integrates and further develops the legal, scientific, geo-information, and administrative aspects of the process of building modern GIS for registration, data management, scientific and other analyses, and assessment procedures that concern our knowledge of the past and the preservation of archaeological heritage of Bulgaria. This is a pioneering research scheme and the effects of this novel system will improve the accountability of various administrative, social, and economic factors that help archaeologists and the other specialists from the earth sciences to assess the impact of the land-use on archaeological sites. The possibility for manipulating the probability interval of occurrences of archaeological events and the comparisons of these intervals within an entire micro-region constitute an excellent tool for 'visualizing' common and particular threats to destruction of the archaeological heritage. With this analytical procedure we increase the precision not only of the methods of field survey, registration and documentation but also of the analytical tools for assessment of the otherwise complex interplay of human and natural factors responsible for preservation of all the traces left by past human activities.

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Unwrapping of a column on the base of automatically generated surface models

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Abstract: Digital stereo-photogrammetry allows users an automatic evaluation of the spatial dimension and the surface texture of objects. The integration of image analysis techniques simplifies the automation of evaluation of large image sets and offers high accuracy (HENZE et al. 2006). Due to the substantial similarities of stereoscopic image pairs, correlation techniques provide measurements of subpixel precision for corresponding image points.

By automatic or manual single point measurement of model- and 3D-reference points in the images the stereo models are orientated automatically.

An adapted expansion- and matching algorithm offers the possibility to scan the object surface automatically. The result is a three dimensional point cloud, the scan resolution depends on image quality.

With help of a triangulation algorithm a digital surface model (DSM) can be created. The texturing can be made automatically by the previously used images. It is possible to texture the surface model in a direct way or to generate orthophotos automatical with support of a DSM.

A great advantage is the possibility to control the accuracy and quality of the 3D-object documentation with the resolution of the images. The procedure described here is implemented in the software metigo 3D.

In january 2011 different kinds of objects (floors and facades) were documentated by stereo models with the aim to generate orthophotos at the site of Athribis near the modern village of Nag' el-Shaykh Hamad in a project of University of Tübingen (Institute for the cultures of the ancient Orient (IANES) Department of Egyptology).

The column shown in this paper, was covered by 9 stereo models (image pairs) and 31 reference points were measured by a tacheometer. For each stereo model a digital surface model was generated like described above.

In combination of these surface models and a user defined unwrapping cylinder a true to scale image plan with resolution of 300 dpi and scale of 1:10 was created. The aim was to create a 2D true to scale image plan, that can be used as mapping base in the fields of building research and restoration.

Keywords: 3d-object documentation, textured surface model, orthophotos, image matching, point cloud.

Image recording

Two digital reflex cameras Canon EOS 5D Mark II were used for 3D-evaluation on the basis of stereo models in an image set at the shown object. These cameras were previously calibrated on two focal lengths (24mm und 50mm).

(Alternatively usable camera systems are Nikon D700 or Sony Alpha 950 as a digital reflex camera with full frame sensor.)

Using a receiving rail (on a tripod), where both cameras have been attached, a set of stereo models was taken. Additional three dimensional reference points at the object have been measured by a tacheometer. The accuracy of evaluation can be influenced by image quality and image scale.
According to the expierience of recording stereo models the ratio of camera basis (distance between both cameras) to the recording distance to the object should be in the range of 1:5 and 1:7. That means for a recording distance of 5 to 7 metre the camera basis should be 1 metre.
Another recording configuration for plastic objects can be the usage of a rotation plate and the recording of single images in suitable step size. The images can be taken by hand too.

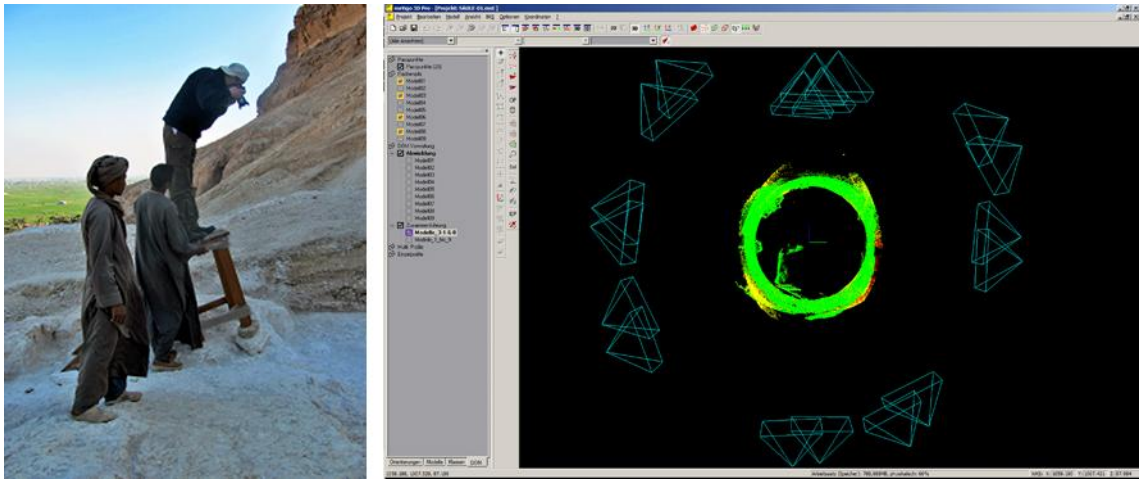

Fig. 1 – Left: recording configuration on site, right: view on top of column (camera positions and coloured point cloud).

Automated model assignment, automated model orientation

After creating a project in the software the evaluation accuracy and resolution are defined and the images are loaded into the project. The inner orientation is established for every image by linking the images to the corresponding camera.
Identical points in the images (identical points at the object) are automatically detected by the evaluation software. On the basis of these points the recording configuration of the images is analysed, with the aim to detect suitable pairs of images or stereo models. In this process the offset vectors of the identical points in each image pair are analysed (parallel recording direction, a large region of overlap). As well the manual creation of stereo models is possible.
The relative orientation of both images of the stereo model is calculated on the basis of the known identical points. If there are not enough identical points for model orientation, additional image coordinates can be measured by hand. Here interactive matching functionallity is useable, so there is a high accuracy for point measurement with subpixel precision.
By using proper filter strategies during the calculation of the relative orientation incorrect model coordinates are detected and removed.
The absolute orientation can be made with the defined distance at the object, the distance of camera basis or by reference coordinates that were measured by a tacheometer. Ideally and for large image sets the

usage of coordinates that were measured by a tacheometer is recommended. There are different kinds of matching modes in the evaluation software for signalised reference points (circle area, black white targets). By measurement of reference points in the first stereo model the absolute orientation of this stereo model into an object coordinate system is calculated. If there is enough overlapping of the stereo models to each other, the absolute orientation can be transferred automatically to the contiguous stereo models.
Therefore a relation graph, that describes the arrangement of the stereo models, is generated with the help of the existing idetical points.
In the absence or insufficient relation / overlapping of the stereo models, for each model reference points can be measured and the absolute orientation can be calculated interactively.

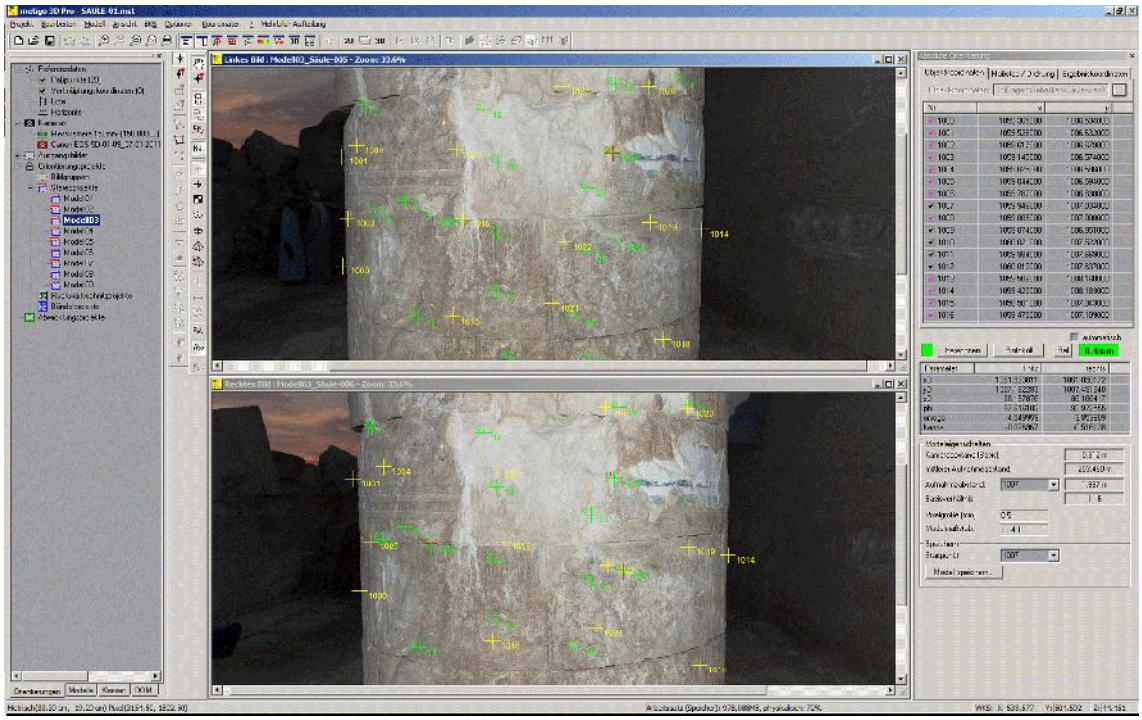

Fig. 2 – Absolute orientated stereo model (green image coordinate: used control point; yellow image coordinate: projected reference point).

Automated generation of a point cloud

Due to the substantial similarities of stereoscopic image pairs, correlation techniques provide measurements of subpixel precision for corresponding image points.
In addition to the single-point measurement object surfaces can be “scanned” with appropriate expansion algorithms (VETTER 2005).
With consideration of the evaluation accuracy for every stereo model the right step size (point distance) for matching is determined in dependence of the images’ scale. To avoid “scanning” in uninteresting image areas (e.g. sky) evaluation areas can be defined by measuring polygons. For large projects (many stereo models) the generation of point clouds can be made with batch processing.
The result for each stereo model is a coloured point cloud. Beside the colouring with the object texture by using pixel colours of the images that are used for matching the point cloud can be coloured by error. Here,

for every matched point the error is calculated by photogrammetric spatial intersection and so the point cloud is coloured according to these errors. Incorrect points are filtered automatically by an adjustable threshold. The colouring by error shows information about the quality of the orientation of the stereo model or an insufficient camera calibration.

The difficulties during the matching process occur in unsharp image areas, homogeneous areas, lighting and shadowing.

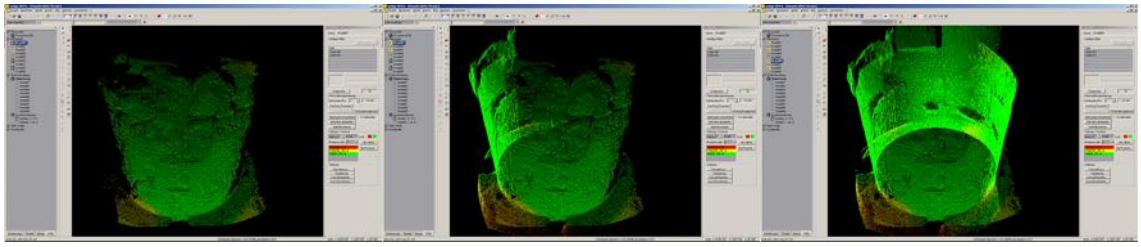

Fig. 3 – Partial point clouds in the 3D window, colouring in dependence of point error (left: front point cloud; middle: front and left point cloud; right: front, left, back and right point cloud).

Automated evaluation of digital surface model

With the help of the integrated Iterative Closest Point algorithm the partial point clouds are transformed by the identical control points and merged to a total point cloud. The algorithms were developed in cooperation with with the Society for the Promotion of Applied Computer Science. During the integration of the ICP algorithms adaptions were made.

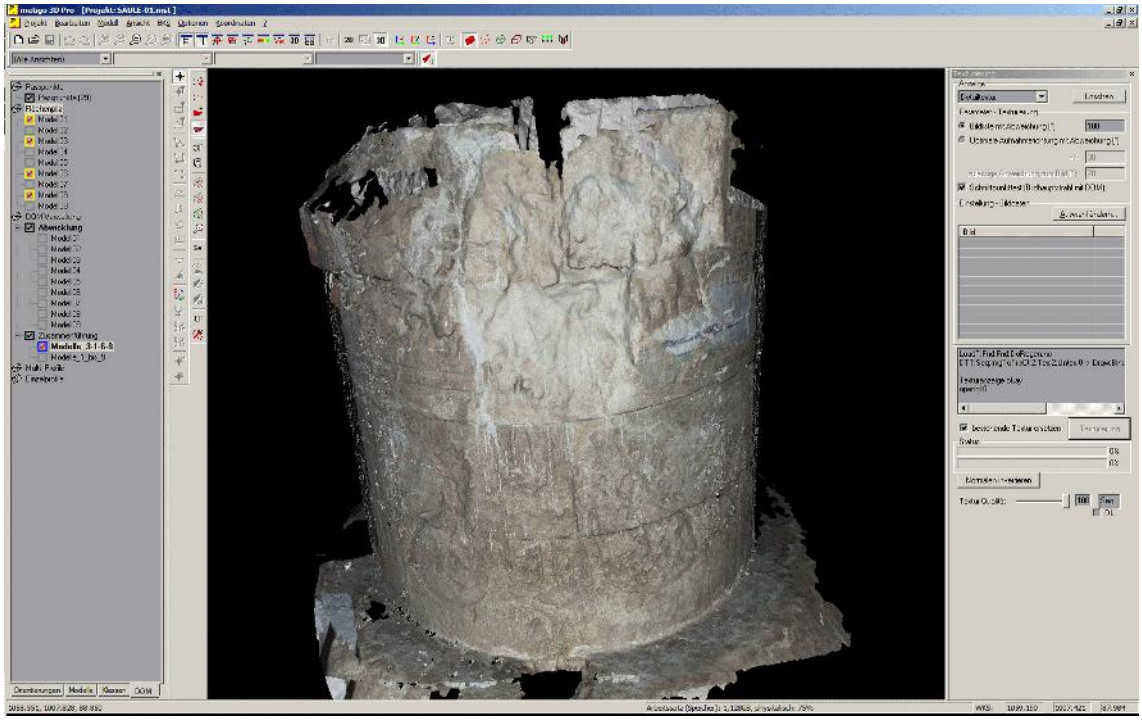

Fig. 4 – 3D-surface model with image texture.

Due to the merge of partial point clouds the resulting point cloud has a higher point density. Using filter strategies, the point cloud is thinned out to the evaluation accuracy in the overlapping areas (HEINRICH 2010).

With a triangulation algorithm (BERNARDINI et al. 1999) a digital surface model is generated on the basis of a point cloud. During the triangulation algorithm a sphere is rolling over the point cloud. For every triple of points that is connected by this sphere a triangle is created.

In a second step, after editing the surface model, the images that were used for matching are mapped on it. Thus a three-dimensional digital documentation is possible. This result can be exported as VRML-file.

This creation of surface model is possible for each partial point cloud as well as for the resulting merged point cloud.

For the creation of large picture assamblies made of ortho photos, it is better to create a single ortho photo for each stereo model (partial point cloud, partial DSM). In a second step these ortho photos are combined with the help of an image processing software, to adapt colour differences and differences in brightness.

Unwrapping/digital ortho projection

The unwrapping and ortho projection can be processed by using a plane, a cylinder or a sectional profile. The position of such a projection geometry has to be described in the coordinate system of the orientated images. For controlling of the right position and orientation of the plane or cylinder, it is shown in each orientated image.

If the object is highly deformed or consists of irregular surface structure the orthogonal projection can be made on the basis of a surface model for a plane as well as for a cylinder.

For the projection of images onto a plane or another unwrapping geometry, user coordinate systems can be defined related to object coordinate system or with the help of a partial set of points (balancing plane). Additional sectional profiles can be extracted and generalized from the existing point cloud or surface model.

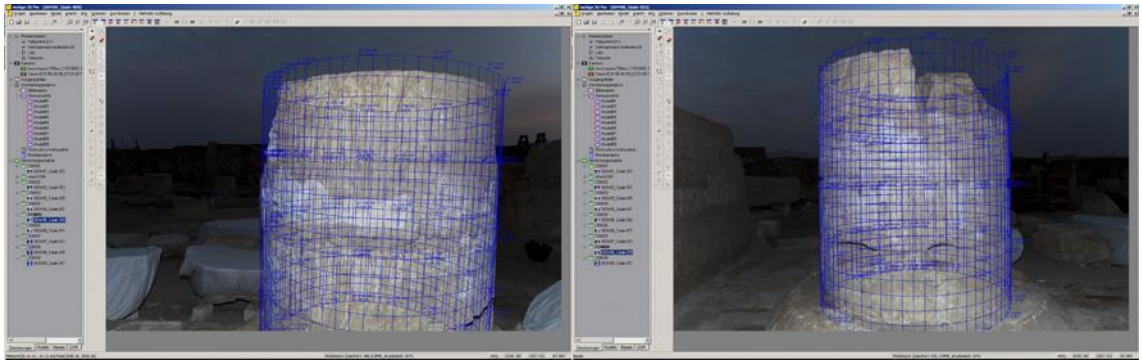

Fig. 5 – Two orientated images with projection of an undwind cylinder (for ortho projection).

After selecting the images for orthogonal projection the image resolution and scale have to be defined. With the help of the orientated stereo models the reproduction scale is calculated and so a suitable scale is proposed.

So for each selected orientated image an true to scale ortho photo is calculated during a batch process. For all images that were projected to the same projection geometry one multi layered TIFF-image is calculated. So the adaption of colour differences and differences in brightness can be done in an image processing software.

Fig. 6 – Unwrapped image plan of column (ortho projection onto cylinder).

Summary

The here shown column was covered with 9 stereo models and round about 31 reference points were measured by a tacheometer. The orienation and evaluation of these stereo models and the shown results were processed with the software metigo *3D*. The final image processing and colour adaption were made with Adobe Photoshop CS5.

The resulting orthophoto, processed in scale 1:10 and 300dpi image resolution, can be used as a 2D mapping basis for the documentation of the object.

The digital surface model can be alternatively textured to use it for 3D mapping. At the moment the 3D mapping is not used in restoring because of practical reasons like the amount of data, printing or data exchange with the final customer.

The advantages of the here shown procedure are the possibility to create surface models and true to scale image plans in a high resoultion. This procedure is applicable for small objects as well as for large facades and can be used in addition to laser scanners, because a laser scanner could not be available in every situation.

According to the parameters of a laser scanner (measurement method, measurement accuracy and noise) they are just usable in specific object dimensions.

The only requirements for the here described procedure are at least one photogrammetically calibrated SLR camera (full frame sensor), the software metigo 3D for image evaluation, matching of point clouds and the ortho projections and Adobe Photoshop for image processing.

The experiences in these projects have shown, that recording configuration, image resolution of the camera and measurement accuracy of reference points (natural and signalised) have to be planned according to the desired result.

Due to the small radius (perspective view at image border conditioned by strong curvature) of the column a better image quality could be achieved with more stereo models.
For the intended scale of 1:10 the usage of signalised reference points is recommended, if they can be put to the object (accessability or damaging of original surface).

Acknowledgement

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Federal Ministry
of Economics
and Technology

on the basis of a decision
by the German Bundestag

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SESSIONS

3D Reconstructions from Urban Surveys

From the small elements to the urban scale: an investigation where petrophysical study of materials and architectural shape analysis try to read a masterplan in the Hadrian’s Villa, Tivoli (Rome, Italy)

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Abstract: Inside the Hadrian’s Villa in Tivoli, it is possible to read multiple networks aimed to create systems for moving people and supplies, to create spectacular spaces, to give welfare and security to the court and to the people living in this urban scale monument. The reading of these networks sometimes is not easy, but the main idea in this project is to start from the small evidences in the single buildings, find rules and solutions to combine them into a global digital survey based on a 3D digital model and then start using this model for the formulation of some hypothesis. The evidences will come from the analysis of the materials (stones, mortars, concretes, bricks) and from the architectonic shapes study. Combining these two parallel paths into the rich digital survey of the area gathered by the “Dipartimento di Architettura” since 2004 it becomes possible to create a multi-level environment aimed to be shared by scholars from different branches to start their analysis. Through a petrophysical study of materials, the macroscopic analyses data of structure wall textures, all linked to the 3D digital documentation based on the use of laser scanner technologies, it’s possible to reconstruct the construction stages of Hadrian's Villa. The petrographic, mineralogical and chemical characterization of the wall and floor mortars and concretes and their physical properties (total and open porosity, real and apparent density, mechanical strength, aggregate granulometry, binder/aggregate ratio, etc.) allowed to classify the function and the compositional variations of the same within the structure of the therms. In parallel to this the study of the architectural shapes, starting from the accurate digital survey, allowed to identify geometric constructions, with variable and constants in the architectural choices, tracing some interesting paths in the deep knowledge of this monument.

Keywords: Roman thermae, Stones, Petrophysical characteristics, Laserscan, 3D modelling.

Overview of this research

The Hadrian’s Villa is a luxurious residence from the Roman Imperial Age, over time it was a laboratory for architectural and artistic creativity, where technological and architectonical innovations were experimented to create an environment characterized by advanced urban and technical solutions. This is also due to the Hadrian interest about architecture showing a particular fondness for the dome structures. The construction of the Villa began in 118 a.C. after the proclamation of Emperor Hadrian. The use to own marvelous residence out of Rome became typical for the Roman Emperors starting from Tiberio (27 a.C.) and the Hadrian’s Villa follows this use in its specific way, being not only an imperial residence but also a place for arts and architectonical experimentations. Various scholars place the main phases of the Villa's construction

as connected to the travels of the Emperor along the Empire boundaries. Observing the ruins and the finds from the Villa it comes out clear the fact that the Villa shows echoes of many different architectural orders, mostly Greek and Egyptian, all these traces are a prove of the will to connect the scale of the Villa to the knowledge of the world experienced by Hadrian.

The constructions continued almost without stops for twenty years until the Hadrian's death in 138 a.C.

The Villa, even if not completed, was used by Hadrian's successors. During the decline of the Roman Empire the Villa fell into disuse being abandoned to its own fate and a long age of decay started to bring down to ruins the whole area. The remains of the monument were discovered again during the Renaissance, but the decay of the monument continued because of the abandon and most of all because of heavy robbery acted to spoil the ruins from the rich statues, sculptures, mosaics, stones, architectural elements and even pipes and bricks. According to the contemporary state of knowledge the Hadrian's Villa is a great complex of over 30 buildings grouped in numerous pavilions scattered in a very large area covering about 300 acres. The whole complex shows the great efforts made in experimentation and how this has caused many time the need to rethink some buildings and to reinvent solutions, a lot of constructions show multiple plan and section choices, the union of different styles and a large number of new and walled openings. The ruins of the Villa were carefully surveyed with digital tools starting from 2004 by the "Dipartimento di Architettura, Disegno, Storia, Progetto" of the Architecture Faculty in Florence. After eight years of activities it's possible to use this large scale survey as the base for further collaborations and experimentation. This new, advanced strategy is aimed to enhance the knowledge about the Villa, putting various scholars, from different disciplines to work toghether on a common ground. The study of single elements characteristics is here the base for start developing some new hypothesis, starting from the geometric shape of some main architectural parts and from the materials used to build this monument.

Fig. 1 – Overall scheme of the digital surveys taken in the Hadrian's Villa by the Florentine unit starting from 2004, the areas are highlighted over the "ancient Villa model" realized by Gismondi in the past century. From left to right, in clockwise order: the "Large Baths", 2004; the "Cento Camerelle", 2005; the "Grande Vestibolo" and of the s.c. "Serapeo", 2005 and 2007; the "Small Baths", 2007–2009; the "Heliocaminus Baths", 2010.

Fig. 2 – The Heliocaminus baths during the survey operations in September 2010.

The work will start from the therms network, where three important building, like the Heliocaminus, the Small and the Great Therms, were erected (Fig. 1, 2). Two units will work on the development of analysis result over the Heliocaminus Therms, one operating according to a “Bottom-Up” process and the other proceding according to a “Top-Down” process. In this paper it will be described the work from the “Bottom-Up” unit.

Analysis of workflow and research activities scheme

The research operated on the structures of the Heliocaminus Thermae in the Hadrian Villa is set according to the diagram illustrated below (Fig. 3 and 4). The whole digital survey was done using a laser scanner and a topographical total station; the long time research inside the Hadrian’s Villa (carried on by the Florentine Department since 2004) is based on a main topographical network, this network allows to reconnect each new digital survey campaign to the previous, creating, a progressive extension of the covered area in a single reference system.

The scanner used in the survey of the Heliocamius Thermae was a Cam2 Faro Photon, with phase shift measuring technology, this allows a high level of detail in a quite long range (from one to forty meters in the Heliocaminus survey) and gave back a very quick operating time, allowing to cover extended parts of the monument in hours.

The overall survey work, characterized by an accuracy around two to four millimeters, was later aligned over the topographical network, combining all the pointclouds together to show a global digital model made of vector points which is capable to describe in details the whole monument. At the same time, the solid topographical network gave the opportunity to combine the Heliocaminus in the large overall system of the

Villa, together with the Large Baths, the Small Baths, the s.c. *Serapeo*, the "Cento Camerelle" and all the other areas taken in years of survey work inside the Hadrian's Villa. While the digital survey was going on, the material sampling survey started to gather a selection of stones, marbles, mortars and fragments all around the ruins of this architecture. This was done after an accurate planning with Dott.ssa Benedetta Adembri, responsible for the whole Hadrian's Villa. In this way only minor and not meaningful parts were sampled, taking out minimal elements to allow further analysis.

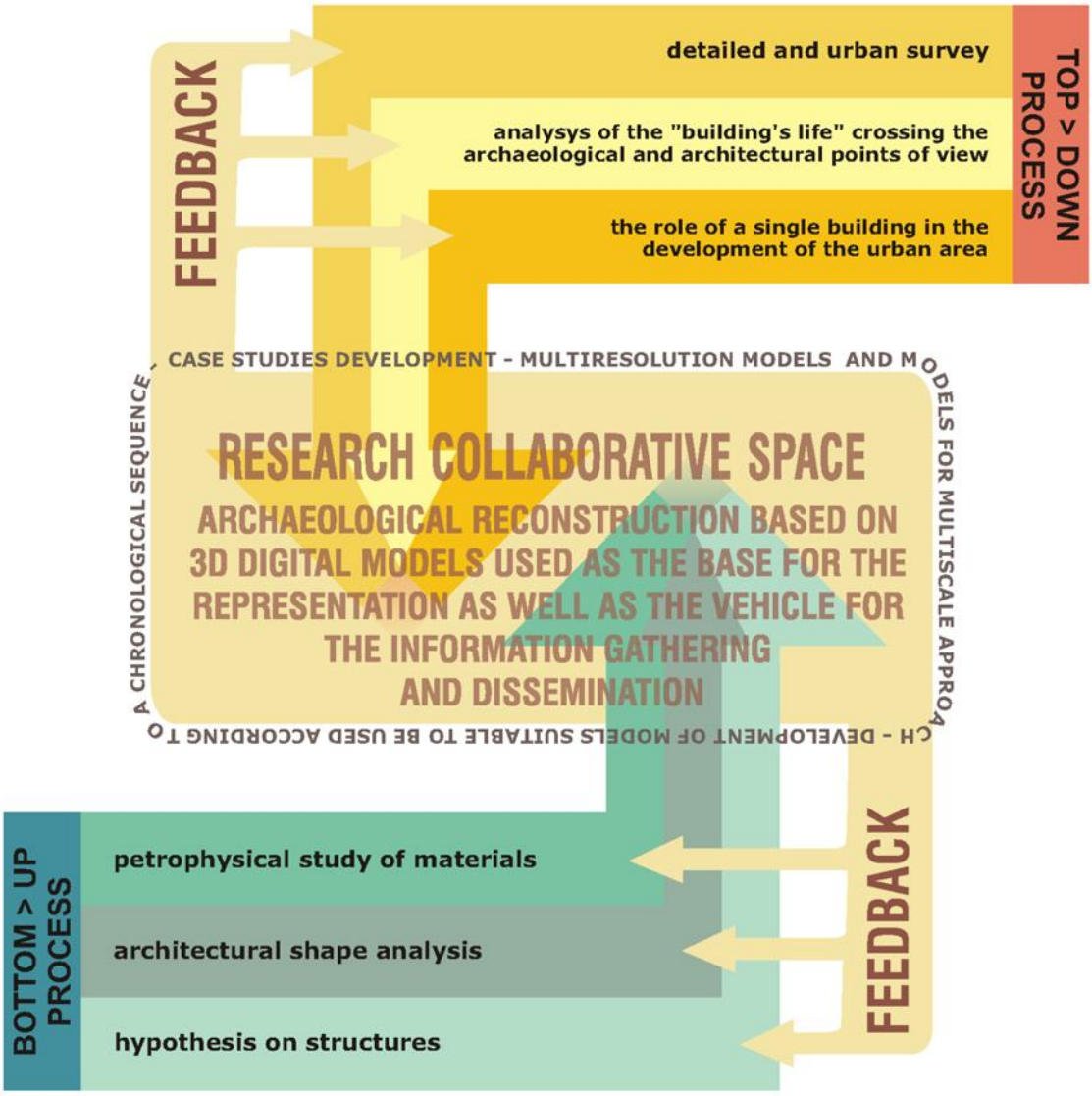


Fig. 3 – The general workflow defined for this research.

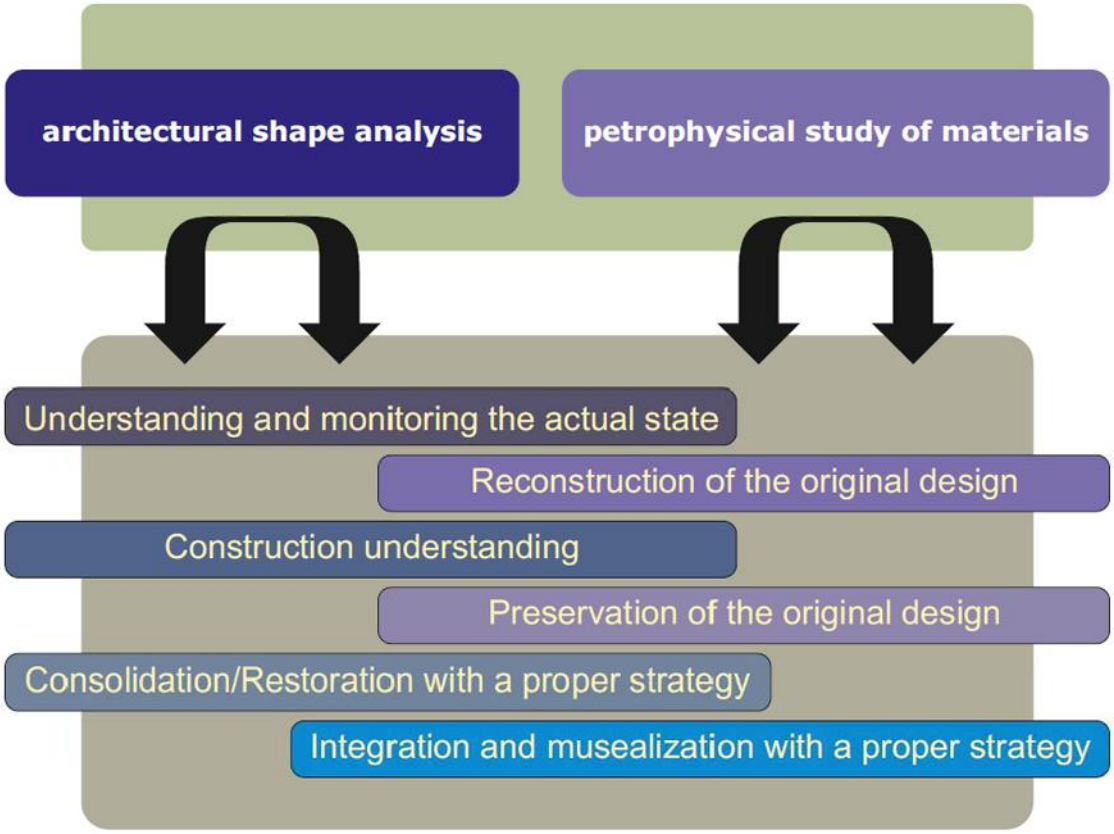


Fig. 4 – The process scheme for the Bottom-Up unit.

The materials used on the Hadrian Villa: the example of the Heliocaminus Thermae (HT)

The materials used in the construction of the Hadrian Villa are very different one from the other, some have a natural origin (i.e. rocks, sands, clays, etc.), other are artificial (i.e. bricks). To make the walls and the interior of HT were used Roman bricks, worked stones, marbles, volcanic rocks taken from local outcrops or from other areas. For the production of mortars, concretes and conglomerates have been used as aggregate the river and volcanic sands, with boulders stones and lateritious fragments (bricks, tiles, pottery). The main object of this research phase is to study the bedding mortars of the bricks (Lat. *Opus Testaceum*) and small ashlars of stones with truncated-pyramidal shape and with a square base, commonly called *cubilia* (Lat. *Opus Reticolatum*), the bedding mortar from the marble coverings, the conglomerates from the floors and the walls showing *coccio-pisto* (Lat. *Opus Signinum*), the concretes from the vaults (Lat. *Opus Caemeticium*), and last, but not least the volcanic rocks used to make the *cubilia*.

The Roman mortars

The mortar is made up by a mixture of binder (lime), water and aggregate (sand and/or pozzolan, and/or lateritious and rock fragments) with variable grain size. The preparation of the mortar used by the Romans was always deeply admired and considered a mysterious technical secret. However, it is very well known while the 'recipe' of preparation was prescribed by Vitruvius (in *De Architectura*, ~25 b.C.) which provides for the use in the mixture of one part lime and three parts of sand (or two parts of quarry or river or sea sand), in

which case, Vitruvius said, for improving the qualities you can add a part of broken tiles, or better still, volcanic sand. This clear approach shows the quality of pozzolan and demonstrate how famous it was during the Roman period, who used it extensively in combination with lime in the preparation of mortar with hydraulic properties was able (i.e.) to set and harden it in an underwater condition, helped by its high resistance to the attack of aggressive aqueous solutions (like the seawater). The pozzolans are volcanic tuffs (pyroclastic rock) in-coherent or semi-coherent composed by tiny granules of glassy substance, more or less vacuolar, subject to associated crystalline granules and sometimes even lithic fragments of different rocks. Hydraulic properties in a mortar were obtained also by mixing the binder with lateritious aggregate, widely used in the conglomerates of the Hadrian Villa. The proportion and the particle size of the natural or artificial aggregates and sand will vary depending on the use of the mortar. For the concrete or conglomerate the binder will be mixed with aggregate coarse (from centimetric to decimetric stone elements, fragments of bricks or tiles) to medium (sand), for the mortar aggregate this value will be from medium to thin (<1 mm), for the plaster it will vary from fine to very fine (<0.3 mm). The percentage of water used in the mixture of the mortar should be in stoichiometric amounts. However, the Roman architects had determined that this was a function of the climate, the rate of evaporation and the type of the binder.

The laying of bricks, mortars and coatings

The wall structure of HT is carried out with various textures using different kind of mortars, Roman bricks, and *cubilia*. The Roman brick was made with clay, decanted and purified in water and degreased with the addition of sand, according to a procedure similar to that used for the ceramic products.

In the construction of the Roman floors it was used to cover them with slabs of stone resting directly on the ground or, in the valuable structures (as the HT), with slabs of marble on the following layers of preparation: the *statumen*, a basal layer of stones laid dry, and preferably arranged vertically to facilitate drainage of water infiltration; the *rudus*, an intermediate layer of lime, sand, gravel or stones that formed a conglomerate; the *nucleus*, a final layer of mortar which served to receive the coating, or it was the coating in itself. In the realization of the mosaics, the laying of small fragments squared occurred, and in some cases, it was placed directly above the *nucleus* layer (i.e. cryptoporticus of Hadrian Villa).

In the laying of slabs of marble on the wall of HT was used to prepare the fund as follows: the *trussilatio*, one or two layers of conglomerate with lateritious fragments adhering to the wall; the *harenata marmor*, a layer of mortar only with sand which was laid directly above the slab of marble. The slabs (with varying thickness) were anchored to the wall according to their weight and to the equilibrium needs. The larger ones and those with a higher weight were secured by iron clamps, the thinner ones were clunged to the wall using a simple layer of mortar. For the concrete (i.e. to realize the vaults of the HT) the coarse aggregate was introduced, at the time of the casting, into the previously prepared mortar with sand only.

This method often led to obtaining an aggregate particle size with a range of the gap between two millimeters (dimension of the sand of mortar) and one centimeter. The Roman plasters of good quality are made up of seven different layers of different composition: a first layer was applied directly on the wall structure and was composed by a coarse aggregate, three layers of mortar with medium sand and finally three layers of mortar mixed with powdered marble were the last to be deployed.

Methodologies and operative phases on the petrophysical study of geomaterials

Criteria and planning activities in the analysis of materials

In petro-archaeometric surveys addressed to the petrophysical and provenance study of materials used in the construction of a structure (i.e. HT) the criteria for the setting and the organization of the work phases are related to objectives. To do this, there must be excellent skills of criticism with regard to analytical methods to use a proper sensitivity for data interpretation, especially in relation to their meaning.

In the archaeometric studies often overlap scientific, historical, cultural and architectural activities, but all is aimed to understanding the material of archaeological and historical-artistic heritage. Among these various disciplines a major role is played by the geomaterial sciences (petrography, mineralogy, geochemistry). The knowledge and basic skills are needed to address specific historical problems (e.g. studies of provenance and movement of geomaterials, technology in different historical period) or conservative (e.g. analysis of the causes of weathering, techniques of preservation, protection and restoration). Some methodological issues related to the activities of the archaeometrical need to be addressed in cooperation with the activities from archaeological, historical and architectural scholars.

Operative phases of work

The researches (sampling, laboratory analysis, data interpretation) on the HT were divided into several phases. The various studies and analytical methods used can be divided according to the following list:

1) Historical research – Includes the study of the bibliography of original archival sources and historical interpretation in order to learn its history and cultural characterization of the construction phases, with particular reference to the environment and information on building materials and their provenance.

2) Architectural reading – Used to analyze the structural aspect (planimetric distribution, building systems, articulation of wall textures, etc.) and elevations of the formal external and internal space.

The purpose of these preliminary stages, under the responsibility of historians, archaeologists and architects, is to compare the data detected with those resulting from subsequent mineral-petrographic and physical analysis of materials, with the aim of determining the quality of the monument and to identify operational practices of work related to the construction site in relation to the lithologies immediately available.

3) Mapping – On the basis of macroscopic characteristics is set to a first recognition of lithotypes, types of mortar and the various macroscopic forms of alteration (dechoesion, alveolation, exfoliation, etc.) according to RACCOMANDAZIONI Nor.Ma.L. 1/88 (1988). This allows later evaluation of the type of analysis performed on the materials (destructive or non destructive) taking into account factors such as size of the moument and its value in relation to the uniqueness/rarity ratio, importance and usefulness of the data.

4) Sampling of the monument and rock outcrops – The samples taken from the monument (according to “RACCOMANDAZIONI Nor.Ma.L. 3/80”, 1980) should be run either as a function of the representativeness of the lithotypes and mortars, and taking into account variables such as altitude above the ground, exposure and distribution of alteration forms found in the mapping phase.

5) Analysis of materials – The destructive analysis allowing the use of different methods: optical microscopy, electron microscopy (SEM), X-ray fluorescence (XRF), diffraction (XRD), porosimetry, etc., that depending on the sample being studied (rock, mortar, brick). In any case the petrographic analysis under the polarizing

microscope in thin section (of the structural, textural and compositional characteristics) represents the starting point for a first classification of the materials found in the HT.
6) Study about the provenance – In this phase on the basis of a comparative analysis will try to find the discriminating petrographic-geochemical-physical markers (MELIS and COLUMBU 1999) and the historical-cultural and archaeological evidences in order to identify areas of supply of geomaterials. This study allows to obtain the data directly but also indirect (for example: financial resources, political situations, distances, roads, etc.)
7) Analysis of the alteration processes – Are studied the minerals of alteration and the main physical properties (porosity, real and bulk density, open porosity, water absorption kinetics, etc.) essential for understanding the weathering processes of rocks and mortar (GARAU et al. 2006). Can be extremely useful also perform the physical-mechanical tests (resistance to compression, flexure, tensile stress) and others specific: frost resistance, permeability to water vapor, anisotropic dilation by water absorption (COLUMBU et al. 2008), ultrasonic velocity related to the degree of anisotropy, etc.

Materials and methods on Heliocaminus Thermae

Sampling

During the September campaign, 56 samples were collected from the structure of HT (Fig. 5, 6). The sampling involved both mortars, stones used for the construction of the structure (*cubilia*), lateritious fragments (bricks, tiles and crushed pottery). To identify the provenance of *cubilia* rocks were also sampled the volcanic outcrops within the archaeological site of Hadrian Villa. Figure 5 shows the main points of sampling. The main criterion was to sample the representative types of mortar with different compositions and functions: bedding mortars of *cubilia* (*Opus Reticolatum*), bedding mortars of bricks (*Opus Testaceum*), bedding mortars of floor coverings (*Marmor pavimentum*) and of wall coverings (*Harenata marmor*), conglomerates with lateritious aggregate of the floors (*Opus Signinum* of *Rudus* or *Nucleus*) and of the wall (*Opus Signinum* of *Trussillatio*), concretes of vaults collapsed (*Opus Caementitium*), see figure 6. The second criterion was sampled mortars having the same function but placed at different heights and/or in diverse environments. This is to be able to observe any differences compositional in the various phases of construction or otherwise for detecting the different modes of production of the mortars, or to highlight any changes of manual labor during the phases of construction. The samples taken from the HT are fragments of material that have volumes including frequently between 5 and 10 cc. From each sample were obtained:
No. 3 specimens pseudo-prismatic (average with size: 15•15•15 mm) on which to determine the physical properties; No.1 specimen for thin sections with a thickness of around 30 µm for the microscopic analyzes; a fragment from which to extract the volcanic granules aggregate for chemical and/or diffraction analysis (for the study of origin of volcanic used) and to perform particle size analysis.

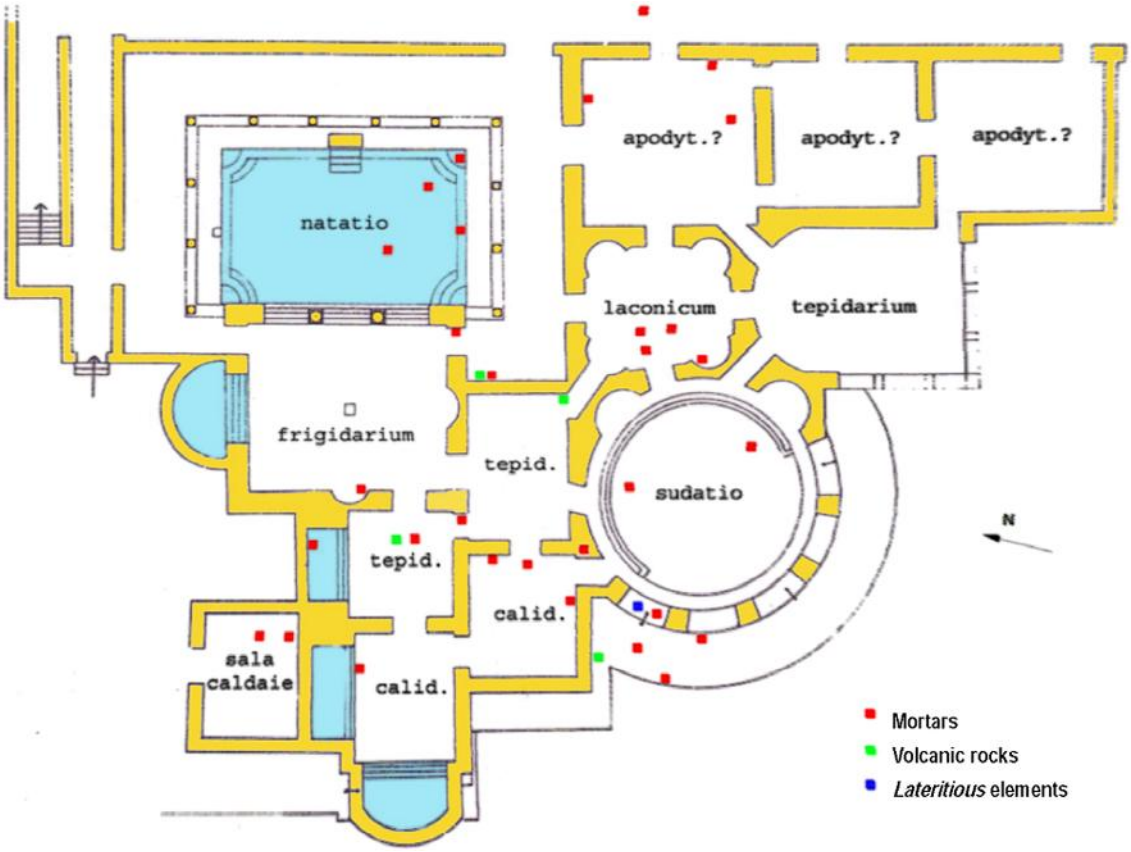


Fig. 5 – The map with the main sampling points of mortar and other materials (bricks, tiles, volcanic rocks of *cubilia*).

Analytical methods on geomaterials

The physical property were determined according to the following methods: the samples were dried at 105±5°C and the dry weight (m_d) was determined. By an automatic Helium pycnometer (Ultrapycnometer 1000, Quantachrome Instruments) the real volumes (V_R) of samples were determined.

Through the use of hydrostatic balance the bulk volumes (V_B) of specimens were measured, where $V_B=V_R+V_P$, with V_P=total volume of open pores. Open porosity to water (Φ_O H_2O), open porosity to helium (Φ_O He), bulk density (ρ_B), real density (ρ_R) were computed as: $\Phi_O H_2O = \{[(m_{sat}-m_d)/\rho_w T_X]/V_B\}\bullet 100$; $\Phi_O He = [(V_B-V_R)/V_B]\bullet 100$; $\rho_B = m_d/V_B$; $\rho_R = m_d/V_R$, where: m_{sat} = wet weight; $\rho_w T_X$ = water density at the temperature T_X considered. The weight imbibition coefficient (IC_W) and the saturation index (SI) were computed as: $IC_W= [(m_{sat}-m_d)/m_d]\bullet 100$; $SI=(\Phi_O H_2O/ \Phi_T)=\{[(m_{sat}-m_d)/ \rho_w T_X]/(V_B-V_R)\}\bullet 100$

By image software and optical microscopy the binder/aggregate ratio of mortars was determined.

The description of the samples was done prior to the macroscopic level, then through a microscope with magnification from 12x to 56x and then at the microscopic level by analyzing thin sections with a polarizing microscope in transmitted light for petrographic determinations of minerals and of textural features of rocks or other parameters. In some cases the recognition of the opaque minerals was performed by reflected light.

Bedding mortars taken between the bricks; 8 Samples Sigle: ADTH 43 / ADTH 21 / ADTH 11 /ADTH 6 ADTH 35

Bedding mortars taken between volcanic ashlars (cubilia); 4Samples; Sigle: ADTH 22/ADTH 23/ADTH 46 / ADTH 54

Bedding mortars taken below the marble slabs of the floor (marmor pavimentum); Total samples: 4 Sigle: ADTH 37 / ADTH 34 / ADTH 28 / ADTH 24

Bedding mortars taken below the marble coverings of the walls (harenata marmor); Total samples: 3 Sigle: ADTH 7 / ADTH 31 / ADTH 52

Conglomerates with broken pottery and brick (opus signinum) taken in the layer (nucleus) of the floor below the bedding mortars of the marble slabs; Total samples: 5 Sigle: ADTH 25 / ADTH 15 / ADTH 3/ADTH 33 / ADTH 32

Conglomerates with broken pottery and brick (opus signinum) taken in the layer (trullissatio) of the wall below the bedding mortars (harenata marmor) Total samples: 5 Sigle: ADTH 18/ADTH 26 / ADTH 13 / ADTH 56/ADTH 14

Concrete (opus caementicium) taken from the vaults of the laconium and sudatio collapsed on the floor. 4 Samples; Sigle: ADTH 50/ADTH 12/ADTH 53 / ADTH 9

Volcanic rocks of cubilia used to construct the walls and as aggregate of the mortars; 4 Samples; Sigle: ADTH 22B/ADTH 44B/ADCA 3/ADTH 16B

Fig. 6 – The sampling on the Heliocaminus Thermae: images of mortars, conglomerates and concretes sampled.

Minero-petrographic analysis: preliminary data

The mortars

By analyzing macroscopic and microscopic thin section, the following characteristic of mortar samples were defined: alteration degree, color of components, binder/aggregate ratio, binder composition, presence of lime lumps not extinguished (*calcinaroli*), composition of aggregate and its shape and dimension of granules. The summary data are reported in the Table 1.

MORTAR TYPE	Binder/Aggregte ratio (expressed as volume)	BINDER			AGGREGATE							
					MINERALS					ROCKS		
		Binder composition	Presence of lumps	Color of binder matrix	Hornblende green	Clinopyroxene	Biotite	Opaque	Total minerals	Volcanites	Marbles	Lateritious (bricks, tiles, etc.)
					as volume percent on total of minerals				as volume percent on total of aggregate			
Bedding mortar of bricks	0,31	calcitic	p	w	70	27	np	3	57	43	np	np
Bedding mortar of *cubilia*	0,21		p	w-g	80	13	5	2	54	46	np	np
Bedding mortar of floor coverings	0,22		p	g	75	14	9	2	54	42	np	4
Bedding mortar of wall coverings	0,13		p	w-g	70	28	np	2	55	45	np	np
Conglomerates of floors	0,13		p	w-g	61	36	1	2	~48	40	<<1	12
Conglomerates of walls	0,11		p	w-g	58	33	6	3	~41	37	<<1	22
Concretes of vaults	0,24		p	w-g	60	36	3	1	~59	41	<<1	np

Tab. 1 – Composizional charateristics of binder and aggregate of ther mortars. Legend of abbreviations: p = presence; n.p.= not present; w = white; g = grey.

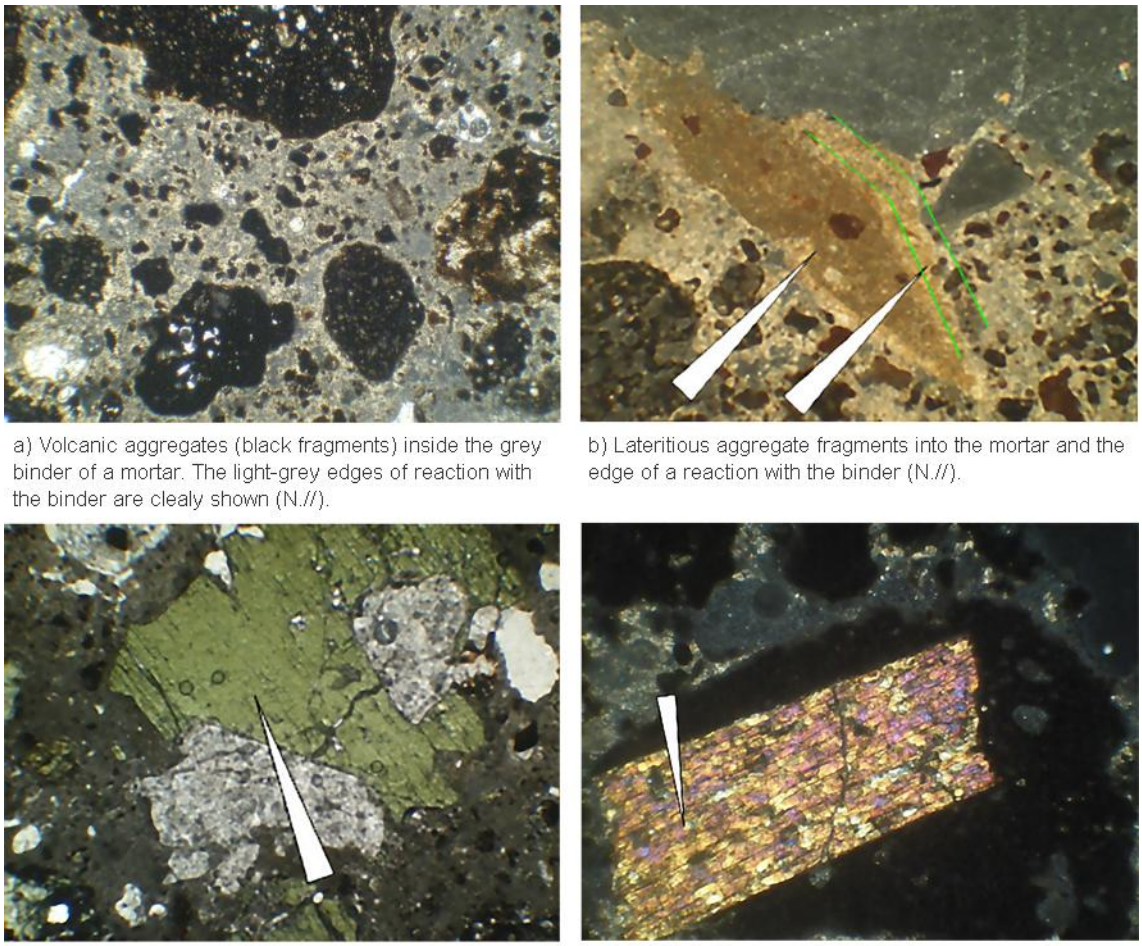
Description of the binder

A feature common to the mortars, except some samples as a function of their use, is the pozzolanic lime composition which gives different degrees of hydraulicity depending on the type and quantity of the aggregate. The binder has colors ranging from light gray to white in the inner portions, while on the surfaces exposed to the outside, due to the processes of alteration, shows more intense colors up to dark gray. The alteration is also seen in thin section with less iridescence of the binder in the altered layer with a thickness in some cases up to 1.5 mm. There is the frequent presence of lumps with dimensions from submillimetre to 6 mm, but in some samples the binder appears to be more homogeneous without the presence of lumps. Organic patinas are often present with a color from gray-black (e.g. molds) to light green to white to yellow (e.g. mosses, lichens, etc.) which produce alteration in surface with maximum thickness of about 1 mm.

Description of the aggregate

In all samples of the mortars (Tab. 1) the aggregate is composed of rock fragments (mostly volcanic and seldom metamorphic) and single crystalline phases (crystal-clasts). Are also present other lateritious components (crushed bricks, tiles, pottery) as function of the kind of the mortar. The volcanic aggregate is composed of the alkaline rocks belonging to the Roman Magmatic Province (PECCERILLO 2005) within the

ultrapotassic serie (HKS) that varies from leucitic basanite to leucitic tephrite to leucite phonolitic tephrite to leucite tephritic phonolite and leucitite to potassic phonolite.



a) Volcanic aggregates (black fragments) inside the grey binder of a mortar. The light-grey edges of reaction with the binder are clealy shown (N.//).

b) Lateritious aggregate fragments into the mortar and the edge of a reaction with the binder (N.//).

c) Crystal-clast of green hornblende immersed into the mortar (N.//).

d) Phenocryst of clinopyroxene into a fragment of volcanic aggregate (N.+).

Fig. 7 – Photos of mortars, fragments of volcanic and lateritious aggregates, crystal-clast at the polarizing optical microscope. Legend: N.// = parallel Nicol; N.+ = cross Nicol).

From preliminary data, there are two types of volcanic aggregates. In the first type there is the presence of plagioclase, clinopyroxene, leucite, olivine (often altered in hiddingsite), green hornblende, biotite, opaque. This aggregate has predominantly sub-spherical shapes, variable porosity and un color from grey-red to grey-black and is present in all the mortars with greater frequency. The fragments have clear edges of reaction with the binder (Fig. 7a). The second type of volcanic aggregate is a rock composed essentially of clinopyroxenes and leucite. The feldspars are absent or rare. In the aggregate of crystal-clasts are present opaque (with circular shape, is probably magnetite or Ti-magnetite), clinopyroxene, biotite, green hornblende (Fig. 7c), olivine, rare K-feldspar. The lateritious aggregate has almost always angular shapes with various physical characteristics. The average porosity ranges from 5% to 30% and the color from rust-red to pink-orange to yellow-ocher. Considered that: a) the porosity depends on the shaping of lateritious bricks and characteristics of raw materials and mixtures; b) the color depends on the composition (mainly to the presence of ferric oxide, FISCHER 1983; VOKE et al. 1992) and firing conditions (temperature gradient,

maximum temperature, oxidizing; VOSKUIL and VAN DER GIESEN 1959; FISCHER 1983; SCHMIDT-REINHOLZ 1985; KREIMEYER 1987; STEPKOWSKA and JEFFERIS 1992), the variabilty of these parameters indicate that the aggregate comes from crushing of various lateritious kinds. This aggregate presents a good reactivity with the lime binder (Fig. 7b). The lateritious fragments with colors that tend to yellow and to pink-orange seem to have a lower reactivity with binder respect to fragments with more intense colors toward the red-rust.

The volcanic rocks of cubilia

It's a piroclastite with medium-low welding, consists of a porous glass matrix in which are incorporated lithic-clasts of varying particle size. Looking at the thin sections under the microscope are evident the edges of reaction of the lhitic-clasts with the glass matrix.

The lithic-clasts of are similar to those found in the aggregate of the mortars but they are less affected. By observations with parallel nicol they have a color reddish-burgundy and gray-black only rarely.

Physical characterization

Among the physical properties, the porosity has a major role in the study of alteration processes. It has a decisive influence on the physical-mechanical resistance of the materials and the mechanisms of absorption of water and consequently on their durability.

The porosity of a mortar are linked to the intrinsic porosity and the granulometric characteristics of the aggregate (shape, size, degree granulometric sorting), to the microstructural and compositional characteristics of the binder, the rules for the mixture (ratio of binder/aggregate, degree of homogeneity of the mixture during the preparation).

MORTAR TYPE	ρ_R	ρ_B	Φ_O H_2O	IC_W	SI
	g/cm^3	g/cm^3	(%)	(%)	(%)
Bedding mortar of bricks	2,56	1,46	39,06	26,67	90,96
Bedding mortar of *cubilia*	2,57	1,42	39,71	27,80	89,59
Bedding mortar of floor coverings	2,63	1,44	41,03	28,70	90,86
Bedding mortar of wall coverings	2,64	1,38	40,17	29,24	83,77
Conglomerates of floors	2,60	1,50	38,23	25,17	90,75
Conglomerates of walls	2,41	1,42	38,16	26,44	93,56
Concretes of vaults	2,63	1,42	41,06	28,89	88,98
Volcanic rocks of *cubilia*	2,57	1,47	37,25	25,80	88,04
Lateritious aggregates	2,17	1,65	31,64	19,30	>100
Volcanic aggregates	2,47	1,65	30,21	19,24	89,13

Tab. 2 – Physical properties of mortars, volcanic rocks of cubilia, lateritious and volcanic aggregates. Legend: ρ_R = real density; ρ_B = bulk density; Φ_O H_2O = water open porosity; IC_W = imbibition coefficient (expressed as weight); SI = saturation index (expressed as volume).

The function of the aggregate is to provide mechanical strength and to reduce and distribute the withdrawal of the mortar, but a high content of aggregate and high angularity of the granules are responsible for the

formation of macroporosity (COLLEPARDI 1993) which tends to increase the permeability of the system and, therefore, the degradation of the material.
Other factors that affect the porosity of the mortars are related to the amount of mixing water, the speed of hydration and the drying conditions.
While the water of hydration is an integral part of the structure of the components of the mortar and, therefore, is not eliminated during the phases of setting and hardening, the evaporation of excess water is a function of temperature and degree of humidity of environment.

Result discussion about the preliminary data

The geomaterials of HT were determined in the following physical properties: real and bulk density, open porosity, imbibition coefficient, saturation index.

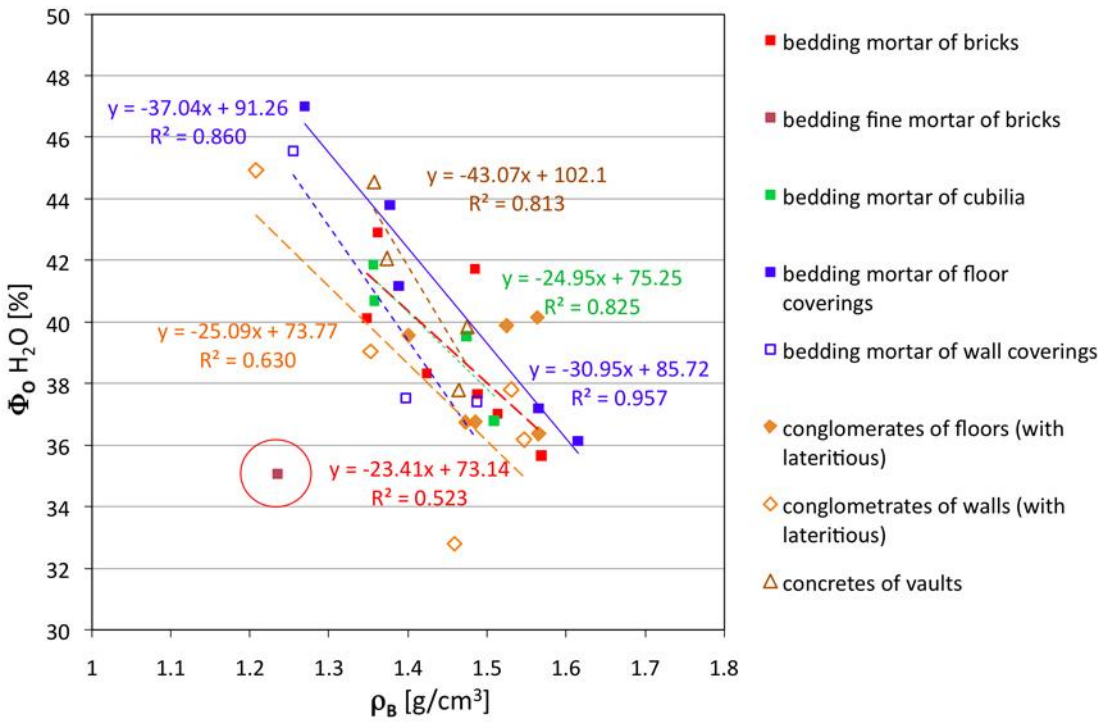


Fig. 8 – Diagram showing bulk density vs water open porosity of mortars.

The physical analysis were performed, as well as on mortar intact, even on lateritious fragments and on volcanic aggregate extracts from the same mortars (Tab. 2). Looking at the graph of figure 8 it is noticed a complete overlap between the sample populations. Except for two samples (one conglomerates and one not significant bedding mortar of bricks which has a ratio of binder/aggregate and a grain size and a microstructure completely different than other mortars), observed high values of water open porosity ranging between 35% and 47%, with average values ranging between 37% and 41%. Considered that the porosity of the aggregate has lower average values (between 30% and 32%, Tab. 2) is likely to assume a high porosity of the binder matrix of specimens analyzed. The coefficients of correlation (R^2) between water open porosity and bulk density are different in the various populations of samples. Due to a more homogeneous aggregate

the bedding mortars of marble coverings of floors and walls and the bedding mortars of cubilia show high correlation coefficients with values between 0.83 e 0.96. The bedding mortars of bricks have a low value (0.53) due to a sample with anomalous values of porosity and density; in fact, without this sample the coefficient would be 0.81. The concrete of vaults has a high coefficient (0.82) because the samples include only the mortar without the coarse aggregate component while the conglomerates. On the basis of a comparison of the average values (Tab. 2) it is observed that the conglomerates have the less values of water open porosity while the concretes tend to be more porous (Fig. 8); this is due probably to the casting of concrete which provides to mix the mortar with the coarse and medium aggregate. This latter is poorly assorted and then consequently leads to an increase of porosity (COLLEPARDI 1993).

The determination of binder/aggregate ratios showed substantial differences in relation to the function of the mortar (Fig. 9) with high values in the bedding mortars of bricks because they have the function to entice but also to level any defects of the bricks (e.g. lack of flatness of the faces).

By contrast, the conglomerates show more lower values of this ratio, due to the high presence of lateritious aggregates. The conglomerates of the walls (*Opus Signinum* of *Trullissatio*) and of the floors (*Opus Signinum* of *Rudus*) have similar porosity but different real and bulk density (Fig. 10).

The layer of *Trullissatio*, where the main function is to prevent the leakage of saline efflorescence coming to capillary rise of water from the foundations and/or directly from soils, has a density lower due to the presence of lateritious aggregate heterogeneous, more porous, probably derived from production waste and with low real density (2.17 g/cm^3). The conglomerates of the floors instead given their primary function of structural bearing, show higher values due to probably the use of a lateritious aggregate more compact, less porous, with higher quality. The mortars and the samples of volcanic aggregate are positioned below the line with SI (saturation index) = 100% (Fig. 11). The samples of lateritius aggregate are placed above this line. It will then investigate this aspect. The graph in figure 12 shows the mechanical strength versus the water resistance (measured as decohesion as weight % loss) after total immersion for ten days. The conglomerates show lower percentages of weight loss (from 0.02 to 0.17), showing a good quality and hydraulic characteristics.

The aggregates of volcanic rocks in the concretes have higher values of weight loss due to physical decohesion, like the pyroclastic rocks from local outcrops due to the low degree of welding (it depends on their volcanic emplacement).

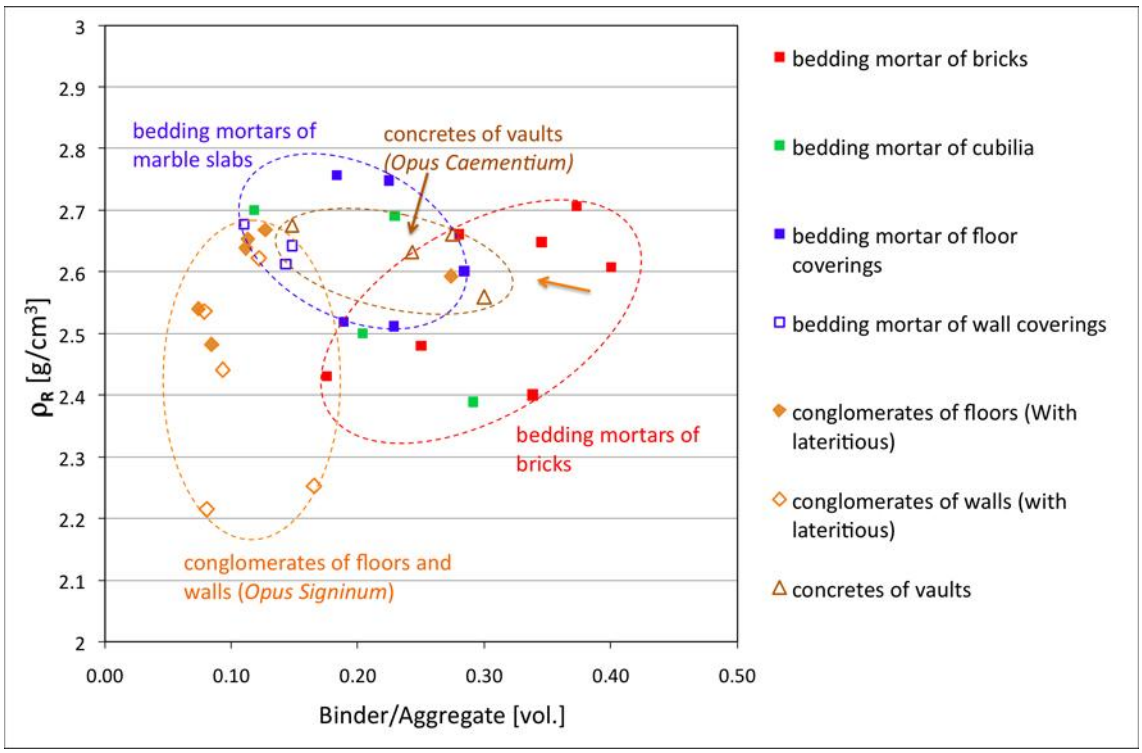


Fig. 9 – Diagram showing binder/aggregate ratio vs real density of mortars.

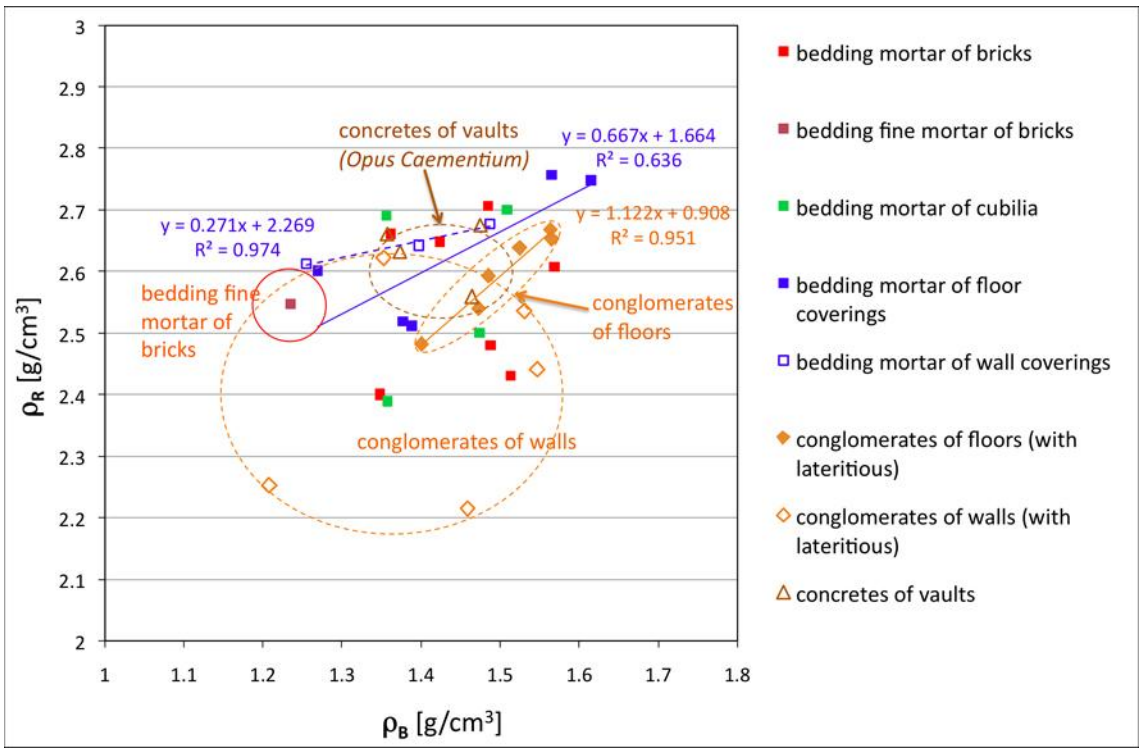


Fig. 10 – Diagram showing bulk density vs real density of mortars.

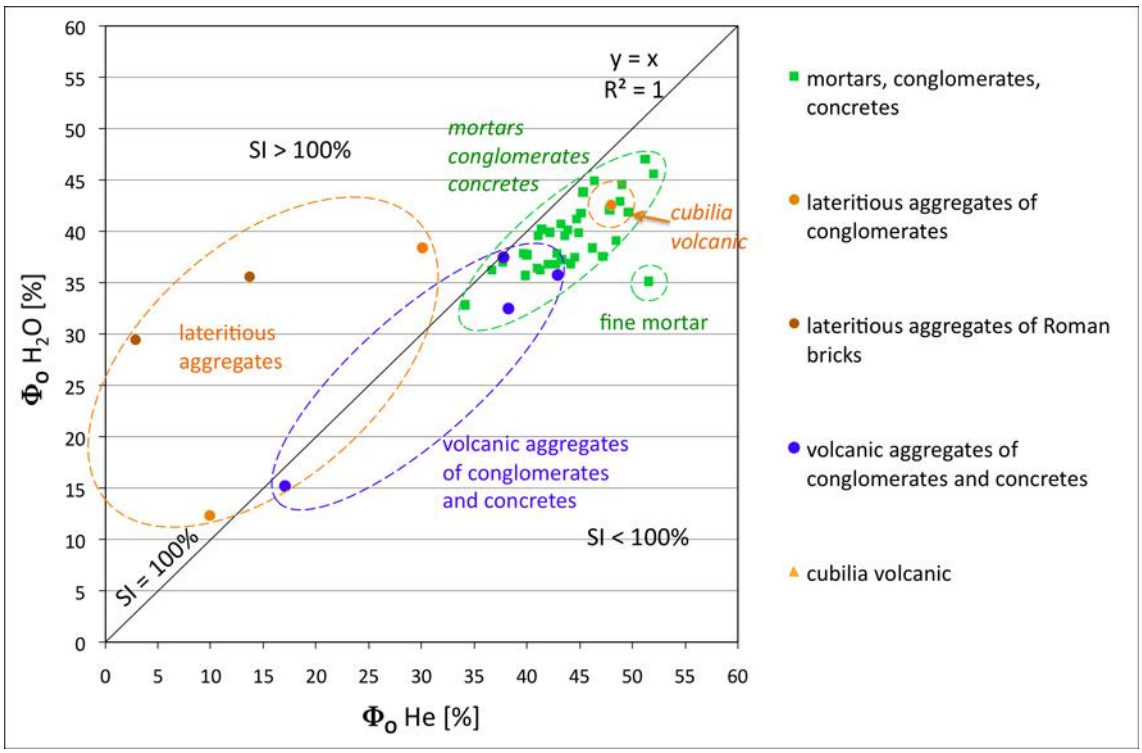


Fig. 11 – Diagram showing helium open porosity vs water open porosity of mortars, aggregate fragments and cubilia volcanic.

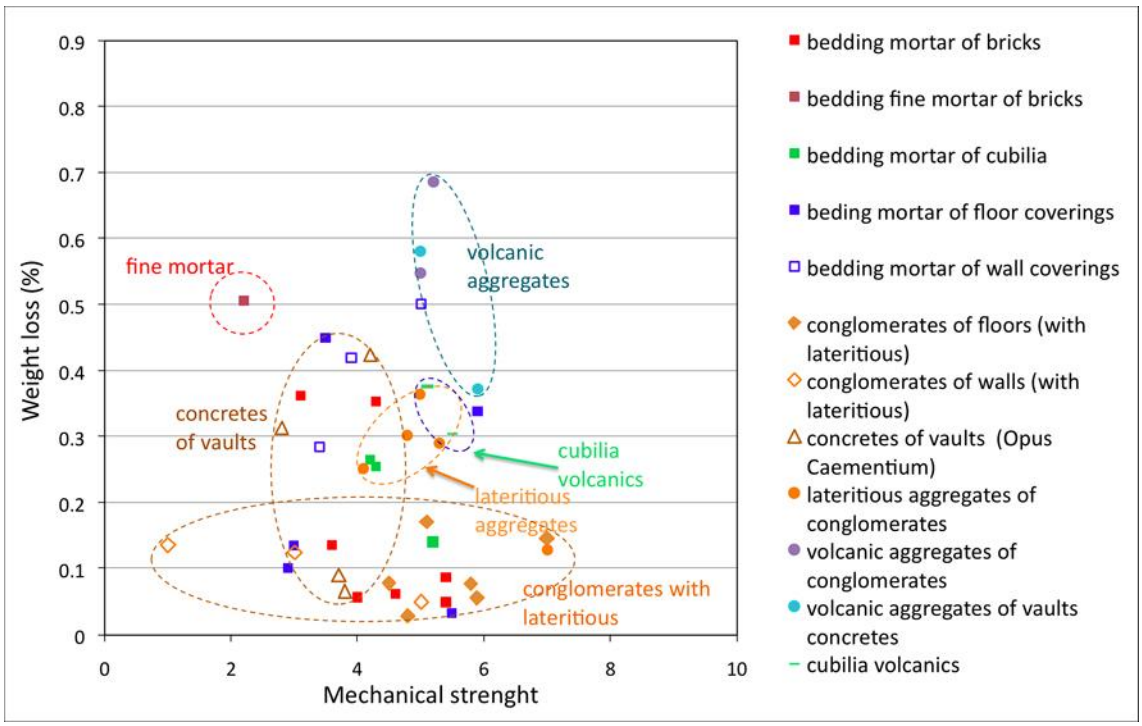


Fig. 12 – Diagram showing mechanical strenght (determined as resistance to scratching with scale from 0 to 10) of mortars, aggregate fragments and cubilia volcanic.

The combination of laser-scanner and petro-physical characterization of materials

The following step was to go back to the digital survey (Fig. 13, 14, 15) and make a try bringing back all the geological/materials information taken from the samples in the three dimensional space of the pointcloud. This was done using the Leica Cyclone software and using its tagging function to add notes to the pointcloud. Each tag is here added to a single point in the pointcloud, so it was quite easy to locate the sample according to the original notes taken during the on the ground operations. The overall result is a sort of addictional "cloud" the set of information taken from the samples are added in their extended form, with all the data organized in a table associated to the tag.

In this way it became possible to associate the information from the samples to section slicing, three dimensional views and any kind of drawing taken from the original dataset. Overall the enhanced pointcloud is in itself a better document about the state of the knowledge about the Heliocaminus Thermae, giving useful information to the archaeologist and being capable to suggest and to confirm hypothesis and theories about the development of this complex building.

Fig. 13 – Digital Survey 2010. Pointcloud dataset, horizontal section.

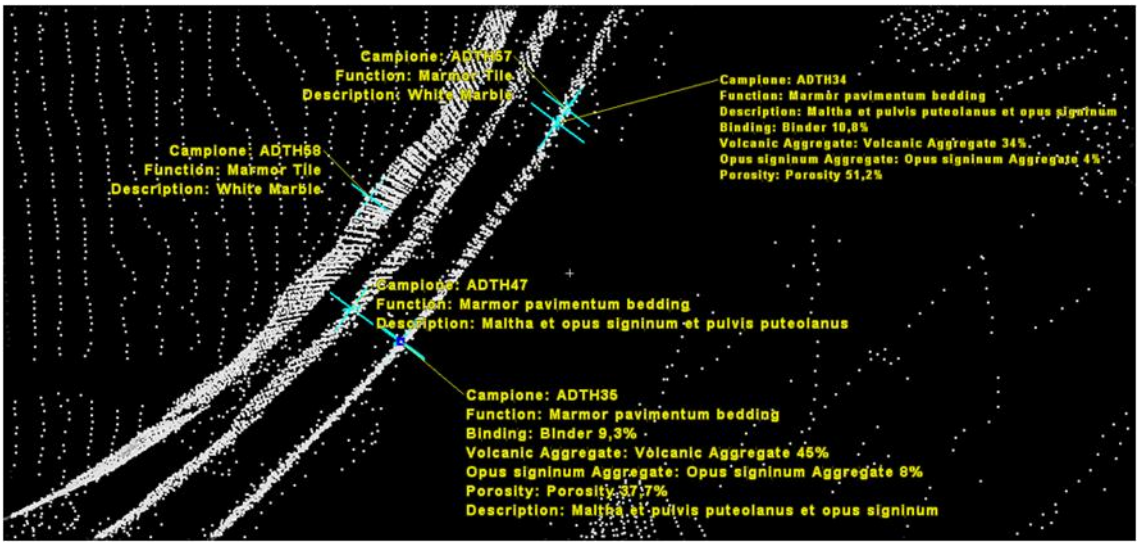


Fig. 14 – Digital Survey 2010. Pointcloud dataset, details with the sampling added in it.

Fig. 15 – Digital Survey 2010. Pointcloud dataset, details with the sampling added in it.

Conclusions

The study of the materials used in realization of ancient structures in relation to their function within the same structure can be an important contribution to the understanding of the construction processes of the monuments that have come to us in precarious conditions or often incomplete. It can be traced, for example, the reconstruction of the various construction phases, the criteria used in the choice of materials, the technologies used in the production and/or processing of the materials. The study of provenance of raw materials can provide information on trade and international trade flows and indirectly to reconstruct the historical-political-commercial events of that particular political context.

The petrophysical characterization with the historical and architectural-structural analysis and laser-scan survey, have contributed to the knowledge of the technologies of production of mortars and working of stones, the technologies used by building laborers, the criteria that led the emperor Hadrian and manufacturers to the choice of materials and their supply. The analysis of the chemical and mineralogical

composition and of the textural and microstructural aspects of samples taken in the Heliocaminus Thermae, together to the analysis of the main physical properties were of considerable help in understanding:

- method of preparation of the mortars (e.g. ratios binder/aggregate);
- the composition and the technological production of binder;
- the minero-petrographic characteristics of aggregate components;
- provenance of the raw materials and information on the commercial flows of Roman period;
- decay state of materials and the presence of macroscopic alteration forms;
- possibilities to operate restorations using chemical products to stop and/or reduce the decay.

The results allows to support a series of archaeological and architectural indications about reading the structure of these *thermae*. The general construction is homogeneous with respect to architectural and structural issues even if they reveal numerous design variations during construction of the thermae, probably related to construction stages and at different times. Certain elements built for technical purposes, like the furnaces beneath the *sudatio* has never been seriously used. This ago imagine that there may have been design errors regarding the functionality of the heating system of *thermae*. The use and mode of mixing of raw materials (aggregate, binder) in the production of mortar appears to have been correct, according to the standards of the period, but some materials (bricks, tiles, etc.) have different qualities and thus indirectly indicate different productions and supply.

The lateritious aggregate together with volcanic aggregate gave hydraulic characteristics to mortars with a resistance to weathering that allowed us to observe them today. This does not happen with the mortars based only on lime while, following the centuries, it remains in contact with the atmosphere, it may undergo processes of chemical dissolution of the binder carbonate, leading to break up the mortar in itself. However it shows the general Heliocaminus Thermae state of decay. The high porosity (up to 47%) of the mortar samples indicate that there are weathering processes with physical disintegration and partial dissolution of the lime binder.

Credits

Digital survey of the Heliocaminus Therms, 2010, responsible: Giorgio Verdiani.
Operative group Facoltà di Architettura di Firenze: Giorgio Verdiani, Francesco Tioli, Mirco Pucci, Graziano Corsaro, with the collaboration of Alessandro Peruzzi from Area 3D Srl Livorno.
Geomaterial mapping and sampling of the Heliocaminus Therms, 2010, responsible: Stefano Columbu.
All the surveys and sampling taken during the International Museography Workshop Premio Piranesi: responsible for the workshop prof. Pierfederico Caliari.
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Quantity versus Quality in Cultural Heritage Documentation

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Abstract: In June 2010, the Dwelling Unit 7 of the Terrace House 2 in Ephesus, Turkey, was scanned from 172 scanning positions covering the object completely. Altogether, approximately 10 billion laser scanning points and a set of control points were acquired. In order to enable a global registration of the given datasets, we applied a robust 3D filtering method on the individual scans to reduce the amount data. After the registration, the points were merged to one point cloud by means of the same 3D filtering process. The main task of the project was the determination of 2D floor plans and sections and the generation of scaled projections of numerous walls for further archaeological interpretation. For this, we applied manual as well as automated methods. Within this contribution, we discuss the differences in quality and quantity of the two approaches. Special focus is drawn on the qualitative benefit of manual methods with respect to the quantitative benefit of the automated processing methods. While the manual analysis is based on commercial software tools, the automated processing is realized by innovative methods for data selection, projection and filtering in order to achieve the expected results. Additionally, hybrid approaches aiming at introducing as much automation as possible to support the manual work while ensuring high qualitative results are discussed. The conclusion of this contribution is that if large scale documentation of archaeological sites is to be performed, automated data processing is preferred over manual documentation for economic reasons, as long as certain restrictions on the achievable quality are acceptable. Automated processing serves as a reliable foundation for subsequent large scale interpretation of archaeological sites and higher repetition rates.

Keywords: Laser scanning, prospection, automation, mapping, 3D modeling.

Introduction

“To Reach and Unveil the Hidden Spirit of the Town” was the motto of the 16th Conference on Cultural Heritage and New Technologies in Vienna. Replacing “town” by “excavation site”, this motto represents the core idea behind any archaeological excavation aiming at finding new insights about the past based on previously invisible or hidden objects (e.g. DONEUS et al. 2008; CRUTCHLEY 2010). In order to preserve the findings which may become visible for a short period only – this fact is of crucial importance in the case of rescue excavations in urban areas – a proper documentation has highest priority for any archaeological scientist. Especially, as such a documentation represents the foundation for the subsequent interpretation and scientific work.

Manually generated line drawings produced by hand and photographs are the fundamental documentation methods in archaeology (KRINZINGER 2010). The major advantage of these technologies is the fact that

they are like to be carried out by the scientists themselves (easy to use) and they allow for in-field classification, generalization and interpretation – i.e. “From which viewing position should images be taken?”, “Which richness in detail should be achieved when producing a line drawing?”, and similar decisions are already drawn during the data acquisition. Additionally, everyone is familiar with these products. The application of 2D plans is part of our everyday life and photographs preserve the real appearance of objects as they are seen in nature.

Within the past decade, laser scanning emerged as a new technology for the determination of the geometric surface structure of objects (e.g. BARTOS et al. 2011; STUDNICKA et al. 2011). By means of current Terrestrial Laser Scanner (TLS), up to one million points per second are determined in a dense pattern representing the object. Although established in many areas such as reverse engineering, industrial surveying, modeling for visualization purposes, and many more, laser scanning is still not entirely accepted for many archaeological applications. The reasons for that are manifold including additional costs, requirement for an experienced operator and the respective equipment, and, especially, a lack in automated data processing fulfilling the expectations of archaeologists.

Within this contribution, we present automated methods for processing TLS point cloud data in order to support the scientific analysis of archaeological sites. The basis for all documentation products is a robust thinning of the raw point cloud, in order to significantly reduce the amount of data while preserving richness in detail and high accuracy. Due to the high degree of achievable automation, it is possible to process huge datasets and thus to document large sites at comparatively low cost and in a short time. Results are presented, based on data of Dwelling Unit 7 of Terrace House 2 in Ephesus, Turkey. The achievable quality as well as quantitative aspects are discussed with respect to results generated interactively based on the same TLS data.

Methodology and Related Work

TLS instruments can be categorized according to the distance measurement principle used. Instruments based on the pulse roundtrip distance measurement emit a laser pulse and determine the distance based on the runtime of the pulse from the sender to the object and back to the detector. Such instruments typically have sampling rates of up to 150.000 points per second and they allow for measuring distances up to kilometers. For distances at the range of some 10 meters, the single point accuracy is smaller than 5 mm. TLS based on the phase-shift measurement principle allow for a slightly better accuracy (smaller than 2 mm), and for higher sampling rates (up to 1.000.000 points per second) but at smaller maximum distances (up to 100 m but achieving the highest quality up to 10 m only). The highest accuracy (smaller than 0.1 mm) may be achieved by close range scanners which in general project a light profile or a pattern on the object’s surface and determine the shape of the surface based on this pattern recorded by CCD-cameras and evaluated using the photogrammetric stereo-matching principle. Economically it is generally not feasible to use such scanners for huge objects due to their restricted field of view (typically up to 40 by 40°) and their restricted maximum measurement distance (some meters).

We propose the application of phase-shift TLS as they allow for high point densities due to their high sampling rates. This enables increasing the achievable accuracy by means of averaging neighboring points

(LICHTI 2004). For this, we propose a highly robust method, called 3D filtering in the following, aiming at reducing the measurement noise significantly while preserving richness in detail. The method is based on the computation of local normal vectors for each point by using its neighboring points. Subsequently, the position of each point is shifted to the position which has the highest probability of being closest to the actual surface, i.e. the mode of the local point density (NOTHEGGER and DORNINGER 2009).

This filtering is applied to every scan. Afterwards, a global registration of the scans is applied. This approach is based on the Iterative Closest Point (ICP) algorithm (RUSINKIEWICZ and LEVOY 2001), minimizing the average distances of overlapping point clouds. Additionally, a network of control points may be considered within a conditioned adjustment calculation in order to assure a consistently high accuracy for the whole dataset. The application of such a network of known (i.e. by tachymetric measurement), possibly signalized control points is advantageous for two reasons: It ensures a global accuracy given by the accuracy served by the network itself, and those points are applicable to determine a good estimation of the global registration by means of manual or semi-automated processing of the data. I.e., knowing three points within each scan allows determining the parameters required for the transformation of local scans into a project coordinate system. Based on this preliminary result, the ICP based approach operates properly.

For the documentation of walls, typically orthogonal projections (i.e. rectified images or ortho images) of the current situation representing the surface structure are used. Such so-called wall views are traditionally generated from line drawings or from geometrically rectified photographs at a target scale (e.g. 1:20) and a target resolution for reproduction (i.e. printed publication). Figure 1 shows typical examples of such documentations as they are commonly used for further archaeological interpretation.

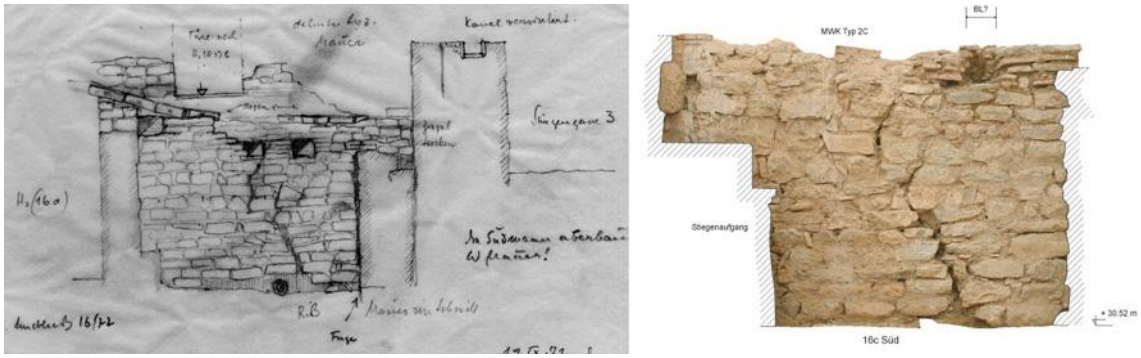

Fig. 1 – Line drawing (left) and rectified true-color photograph of a wall at an excavation site.

As a matter of fact, scanning data represents a surface based on individual points. The achievable resolution defining the maximum scale hence is dependent on the resolution of the given point cloud data and the footprint. Hence, reducing the resolution of the point cloud by means of filtering as proposed may reduce the achievable reproduction-resolution. To overcome this, we propose to assign the given (filtered) points to a grid and thus enabling a mapping of the given point cloud data to a full (i.e. without white pixels) raster representation.

Results and Discussion

We tested the applicability of the proposed methods on TLS data acquired at Dwelling Unit 7 of Terrace House 2 in Ephesos, Turkey. The building was excavated by the *Austrian Archaeological Institute (ÖAI)* from 1960 to 1985. The insula with 7 dwelling units situated on three terraces was built in the first century AD in the center of the city on the northern slope of the Bülbüldagh. After several reconstruction phases, it was abandoned after an earthquake in 263 AD. Today, it is the best maintained antique building in the eastern Mediterranean region. It gives an extraordinary insight to the way of living of the upper class people at Ephesus in the second and third century AD. To preserve this building complex, a modern roof construction was built to protect Terrace House 2. Figure 2 shows Terrace House 2 including the roof construction (left), a photograph of a typical room of the Terrace House (center) and the floor plan of the northern part of the Terrace House containing Dwelling Unit 7 (right, shown in purple).

Fig. 2 – Left: Terrace House 2 with modern roof construction; Center: Photograph of a typical room of Terrace House 2; Right: Floor plan of the northern part of the Terrace House containing Dwelling Unit 7 (shown in purple).

The data acquisition took place in June 2010 using a *Zoller&Fröhlich Imager 5006i* phase-shift laser scanner. Altogether 172 scans with approximately 60 million points per scan were taken. This was done by one operator within a week. Additionally, a network of signalized control points was measured using a tachymeter. The complete point cloud consisted of approximately 10.000 million points covering the archaeological site and its roof construction. For further processing, it was necessary to eliminate the points representing the roof construction. This was done applying a height threshold and by eliminating the remaining points interactively. The left panel of Figure 3 shows a shading of the point cloud after the registration based on the control points has been applied.

In order to improve the quality of the registration locally, a conditioned adjustment using an ICP based approach for minimizing the discrepancies of overlapping scans locally while considering the control point network was applied. For this task, filtered point clouds have been used in order to reduce the computation time. For further processing, we finally generated two point clouds with different resolutions. For local investigations a high density point cloud with 500 million points was generated. For global investigations, i.e. if it was necessary to process all points at once, a point cloud with 100 million points was generated additionally. As described above, robust local normal vectors are a by-product of the 3D filtering process. Based on those normal vectors, points at vertical structures can be determined. The right panel of Figure 3 shows those points height coded.

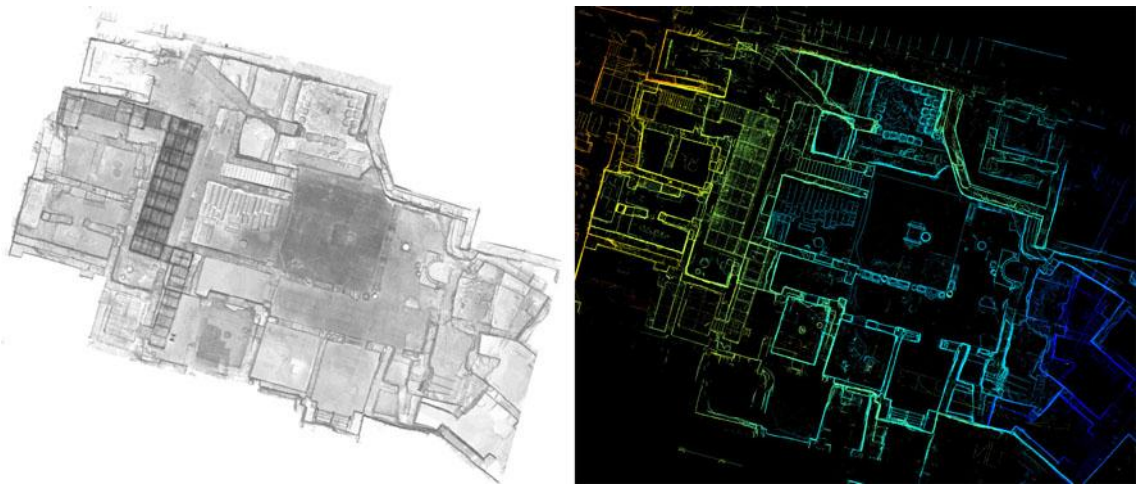

Fig. 3 – TLS point cloud of Dwelling Unit 7. Left: Shading of all points after elimination of points representing the roof construction. Right: Color coding (blue: lower area; red: upper area) of all point at almost vertical structures determined derived from a point cloud after 3D filtering.

For numerous archaeological applications, floor plans are required. Typically such plans are derived from tachymetric measurements. For this, a horizontal profile at a defined height-level is measured in-field. However, several problems may occur: The definition of relevant structures being represented by the plan is done in-field (i.e. generalization) and there is no possibility for validating the correctness during post-processing or to modify the plan later on. The example shown in Figure 4 is representative for those shortcomings. On the one hand, the outline of the biggest room in this scene cannot be determined at one distinct level. The northwestern wall is only visible at 16.20 m (left panel) while the southern structures become visible at higher levels (right panel at 16.60 m). Further on, a discrepancy between the floor plan (violet polygon) and the point cloud (color coded raster profile) occurs in the upper left region of the shown figures. While the rest of the polylines shown have been digitized based on the point cloud, this polyline is part of a previous, tachymetric measurement. Obviously, there was a lateral shift, but at the current situation it is impossible to fix this problem based on the tachymeter measurements alone.

Fig. 4 – Floor plans based on TLS point cloud data digitized at different height levels (f.l.t.r.: 16.20, 16.40, 16.60 m).

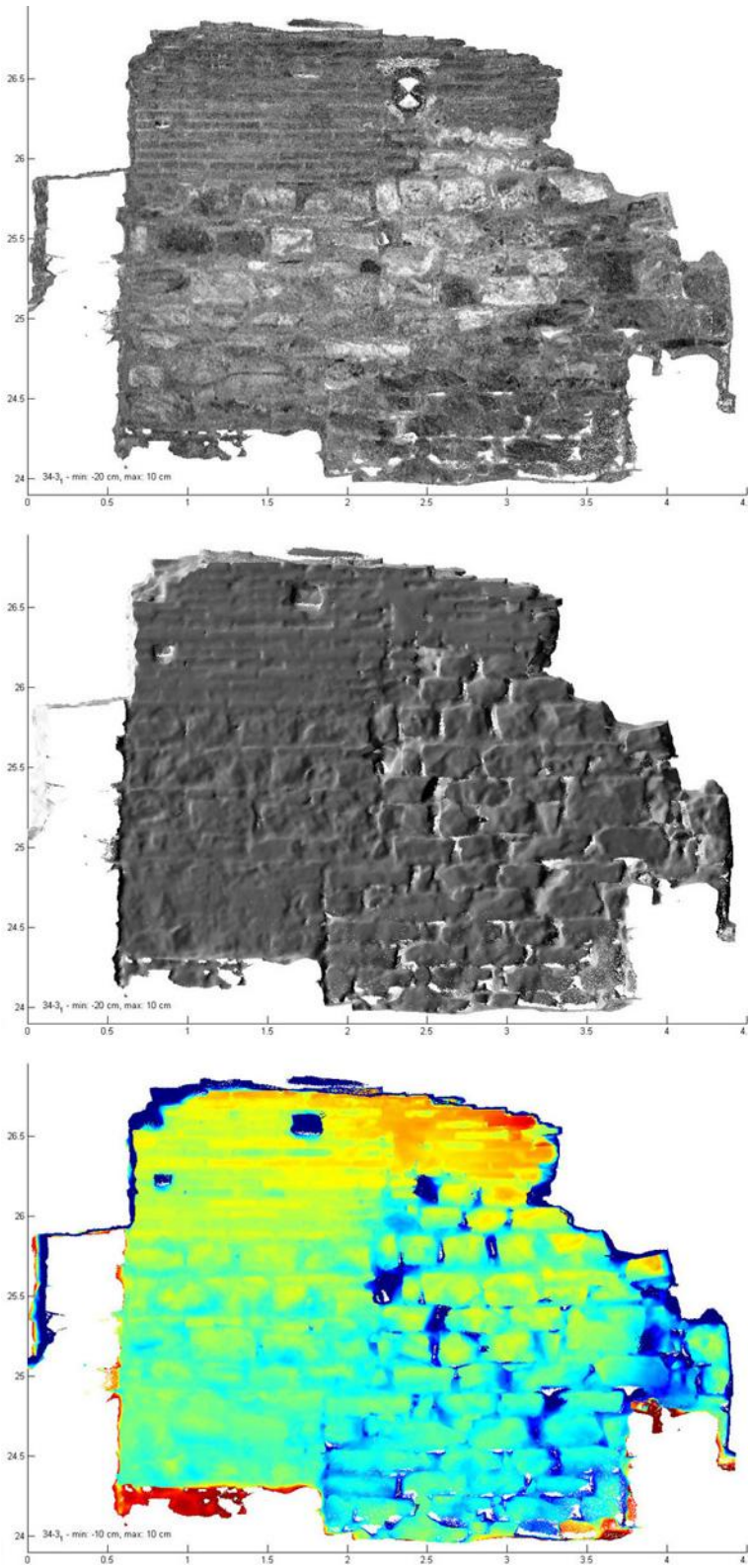

Fig. 5 – Wall views automatically determined from filtered point clouds. Top: Intensity image. Middle: Shaded relief. Bottom: Distances to a best fit plane.

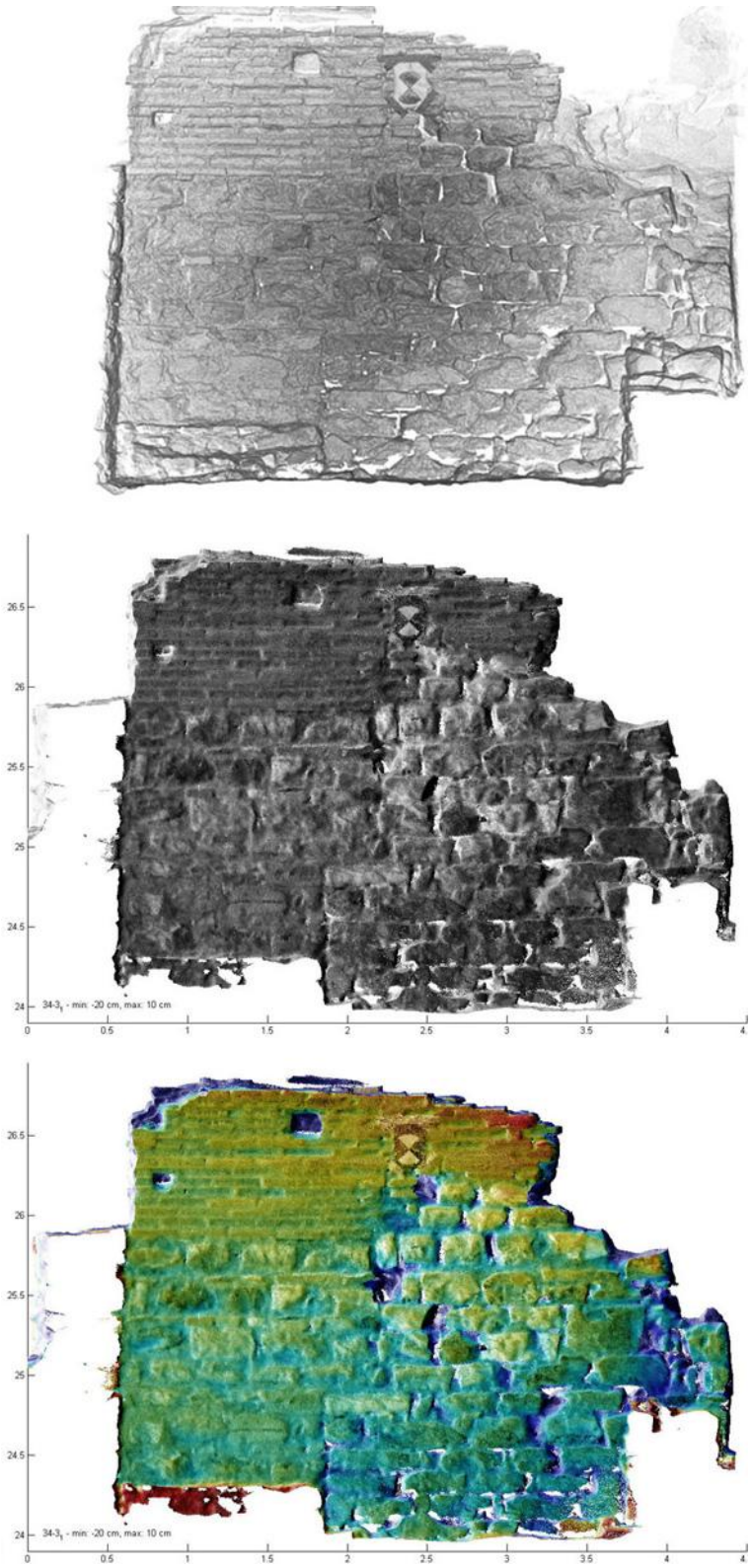

Fig. 6 – Top: Interactively determined wall view combining intensity information and a shaded relief. Middle: Automatically determined wall view combining intensity and shaded relief. Bottom: Automatically determined wall view combining intensity, shaded relief, and distances to a best fit plane.

Additionally to the geometric shape of the object, for each point a respective reflectivity measure, often referred to as intensity value, is determined by TLS. The top panel of Figure 5 shows a wall view of

reflectivity values derived from the filtered point cloud. Compared to the original points, the resolution of the filtered point cloud is reduced and hence may not serve the requirements to generate a continuous image (i.e. without “white” areas) at the dedicated output scale. Anyhow, by defining a respective grid size and by mapping the given points to the grid pixels enables generating continuous representations of the thinned points as well. A shaded relief and a distance map representing the distance of the points to a best fit plane are shown in Figure 5 middle and bottom. To increase the expressiveness of the automatically generated wall views, we calculated combinations of these three layers. The results are shown in Figure 6 (middle: Intensity & shaded relief; bottom: Intensity & shaded relief & distance). A manually generated wall view, based on the original, high density point cloud is shown in Figure 6, top. For this result, all points of the respective scans were selected manually, and a combination of intensity values and shaded relief was computed. In this case, the points were not assigned to a grid representation. This, on the one hand, allowed for a more detailed representation in some local areas where an extremely high point density was available. Anyhow, a more homogenous impression is achievable by means of the automatically, raster based generated wall views.

Despite the qualitative differences between results generated interactively and automatically, we compared the achievable quantity by analyzing the amount of data that can be processed in a given time budget. Table 1 gives an overview on the time required to generate results such as the presented (i.e. floor plans and wall views) interactively and automatically for the whole scene acquired of Dwelling Unit 7. For the floor plans, the difference is not significant. But, the TLS based processing has the major advantage that it enables a verification of the results at any time. For the generation of the wall views, the effort may be significantly reduced by means of automated processing (i.e. from 40 hours to some minutes for the whole scene). It has to be mentioned that in some cases, the automatically generated wall views lack in quality, as disturbing artifacts caused by objects not related to the excavation site (e.g. cables, people passing by, etc.) may not be eliminated properly. This has to be considered either during data acquisition (i.e. during the scanning process) or an interactive “cleaning” of the data has to be performed prior to the automated processing.

Horizontal Profiles (Floor Plans)			
Interactive Processing		*Automated Processing*	
24 hours	Field work (tachymeter)	*8 hours*	Digitizing first version
8 hours	Post processing	*8 hours*	Archaeological adaptations
Result	1 profile; not verifiable	*Result*	Multiple profiles at different heights; verified by point cloud

Wall Views			
Interactive Processing		*Automated Processing*	
40 hours	20 rooms with 4 walls each	*0.2 hours*	Digitize start- and end-point
	selection of points from individual scans and map projection		Automated processing to generate results
Result	80 wall views	*Result*	80 wall views

Tab. 1 – Quantitative comparison of interactive and automated data processing.

Conclusions and Outlook

We demonstrated a set of highly automated methods for processing TLS point clouds for further archaeological interpretation. Based on a processing chain enabling registration and robust filtering of the original scans, the discussed methods are applicable at pre-processed point cloud data, hence making the generation of a surface model (e.g. a triangulation) unnecessary. We compared the automatically generated results with interactively generated ones and showed that there is a very high potential to increase the quantitative output using appropriate data processing methods.

Nevertheless, the local quality of individual products such as wall views may be slightly better if the data is interactively prepared. For example, full automation does not allow for the elimination of locally disturbing objects such as cables or visitors passing by during the data acquisition and therefore, some artifacts may remain within the scene hence impeding the subsequent interpretation. Additionally, it turned out that the interactively generated products match the traditional documentation products like photographs more closely, as the operator may optimize the respective parameters (lightning, color coding, etc.) in order to achieve more pleasant looking results compared to the automated process. Hence the acceptance of interactively generated results is most likely better.

However, the proposed methods have major advantages. As demonstrated by the floor plan example, the proposed, TLS-based approach enables a more selective determination of plans (e.g. using different height levels) and it allows for further interpretation based on the point cloud while direct in-site measurements using a tachymeter do not allow for later on quality validation. Therefore, methods such as the presented ones should be investigated in order to generate new or at least adapted products instead of aiming at the regeneration of traditional ones. Furthermore, the results are more objective as the methodologies and parameters applied are similar for the whole site compared to subjective generalization and selection applied by an operator during interactive data processing.

Summarizing it can be stated that for huge excavation sites such as Ephesus, methods like the proposed ones allow for a significant increase in quantity (i.e. mass production) of documentation, albeit at a slightly decreased quality compared to interactive data processing. Hence, they are well suited for an overall documentation of huge areas while selected regions of special interest should be investigated based on interactively prepared data, at least partially. For urban archaeology, this increased quantity (i.e. fast availability of products) and especially the objectivity with respect to the application of the methods at various sites and carried out by various operators are favorable.

Acknowledgements

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Procedural Modelling of Traditional Balinese Settlements

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Abstract: Traditional Balinese Architecture is known for its extensive rules at both, the microscopic and the macroscopic level, ranging from the design of entire villages to single building elements. These rules are preserved in century old palm leaves, so-called lontars, and were put into practice by the Undagi (traditional "architect") according to the needs of the owner of the building who provides the bodily proportions to parameterize the building rules. These traditional rules lend themselves to the transformation for procedural modelling with design grammars. In architecture design grammars have been used in several examples (e.g. variations of possible Palladian villas, Chinese traditional architecture, historic reconstruction of Rome). Procedural urban modelling appeared more recently with software tools like the CityEngine which have expanded the idea of design grammars and allow for rapid generation of architectural models and entire urban structures of a specific contemporary or historical style. Typically, composition rules are derived by analysing the outer appearance of architectural representations, and lead to formalistic design patterns. The presented approach focuses on the underlying principles of Balinese architecture as well, and tries to formalize design rules reflecting the following concepts: hierarchy of space, cosmological orientation, balanced cosmology, human scale and proportion, open air "court" concept, clarity of structure, truth of materials. As these concepts are adaptable to location as well as the owner, a parametric, rule-based digital model seems well suited to aid this complex design process. A proof of concept was implemented in the CityEngine. This contribution is intended to be a prototypical 3D reconstruction of traditional Balinese settlements, thus helping to understand and preserve the architectural heritage of Bali.

Keywords: Procedural Modelling, Design Grammars, Traditional Balinese Architecture, Architectural Heritage.

Motivation for Procedural Modelling

In many cases archaeological urban reconstruction is based on the surveyed structures of an excavation site, typically containing only fragmented parts of building remains which does not even include a complete floor plan. Additional parts that are generated from the archaeological remains to form a complete building have to be derived using plausible interpretations based on extensive background knowledge about the architecture of underlying culture. Of great value to accomplish this task is the existence of reference objects, either in terms of comparable buildings that are better preserved or by means of widely acknowledged reconstructions. For this process a fundamental knowledge about the architectural style and building principles of the period of interest is necessary.

We focus on automated urban reconstruction based on prototypical lot sizes and urban design principles (like cardinal axes, central squares, typical placement of important sacred and secular buildings). This will be

exemplified for traditional Balinese architecture, since its building principles have been preserved very well over several centuries. Moreover, these building principles are rule-based and rather strict, so they lend themselves perfectly for automated model generation. Procedural modelling is a technique for generative design with a certain set of rules that define how to generate a specific design. This technique can be applied to every scale, ranging from entire settlements to the creation of certain building typologies and even to specific architectural details. In our case the CityEngine seemed to be the most suitable tool for automated model generation to actually implement the Balinese building principles.

In this article we briefly summarize the principles of traditional Balinese architecture. Then we cover procedural modelling in architecture. Finally, we construct rules from the traditional Balinese building principles as basis for our procedural model of Balinese settlements. In order to visualize the approach the rules are implemented in the CityEngine and the results thereof are presented. In the final section a summary of the results is discussed.

Traditional Balinese Architecture

Traditional Balinese architecture is related to Bali-Hindu philosophy that is exhibited in traditional man built environments in Bali. The underlying ancient Balinese knowledge is preserved in lontars (palm leaf manuscripts). In figure 1 the left picture shows a typical lontar next to its engraving tool and traditional ink, the right picture shows the shelf of wooden boxes where the lontars are kept.

Fig. 1 – Lontar (palm leaf manuscript) with engraving tool and “ink”, lontar library in Singaraja.

Contents on the lontars cover various aspects of human life including architecture, religion, healing, arts, history, and so on. Palm leaves are quite endurable and can be preserved for several hundred years.

There have been efforts to translate the contents relating to architecture into Tulisan Bali (today’s Balinese) and Indonesian (BIDJA 2000; DWIJENDRA 2010). Some of the basic principles of traditional Balinese Architecture can also be found in English publications (BUDIHARDJO 1995; EISEMAN 1996). The lontars themselves are kept in the Gedung Kirtya lontar library annex museum in Singaraja, a town in Northern Bali.

Traditional Balinese architecture is based upon seven building principles (BUDIHARDJO 1995) as shown in figure 2 and described below. (1) Tri Angga (hierarchy of space) refers to the threefold quality of space, time, nature, man, and objects as laid out in Hindu-Balinese philosophy. (2) Nawa Sanga Mandala (cosmological orientation) is an orientation system consisting of the eight cardinal directions in combination with the centre created by the mountain sea-axis and the sun movement. (3) “Balanced cosmology” aims at expressing

architecture as a harmonic unification of god, nature and man. (4) The principle of “human scale and proportion” bases dimensions of buildings on the body measurements of the owner. (5) According to the “open air, court concept” buildings usually are open towards nature or include open space and several pavilions within a surrounding wall. (6) “Clarity of structure” clearly display the building’s supporting structure. (7) In the same sense “truth of materials” exhibits the materials used in their natural appearance.

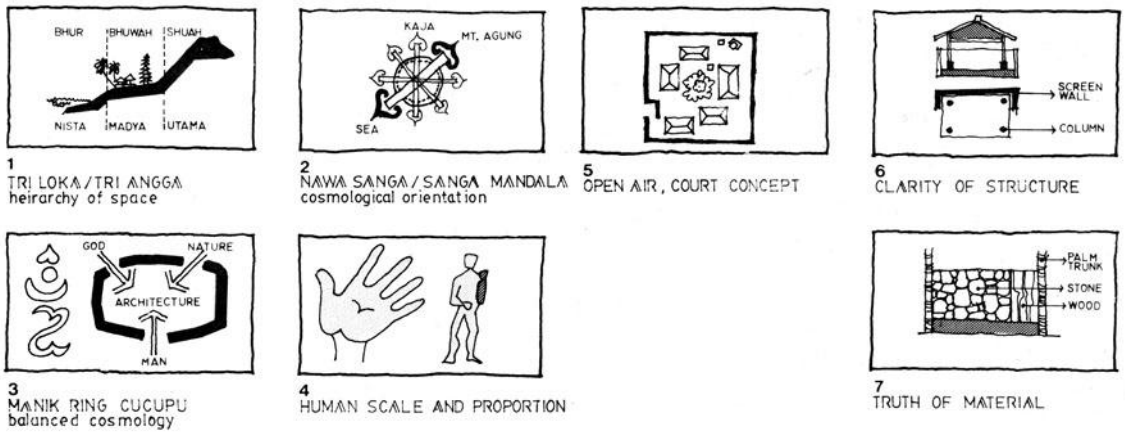

Fig. 2 – Balinese Building Principles, from (BUDIHARDJO 1995).

Typical Design of a Balinese Settlement

A typical village layout according to the traditional building principles is depicted in figure 3. There are three main temples arranged along the mountain-sea axis. The temple of origin (pura puseh) is placed in the part of the settlement that is closest to the predominant mountain in the area or Mt. Agung. The village temple (pura desa) is located in the village centre. The temple of the dead (pura dalem) is located towards the sea. The centre of the settlement is placed at the crossing of two main roads, where a banyan tree is planted as a symbol of life. The central area is used for public buildings, such as the village temple, the palace (if there is any), the market, the bell tower, and the assembly hall. Before bets on cockfights were forbidden, the cockfighting hall was also found in the village centre. Other areas are mainly used for housing.

Typical Layout of a House Compound

A traditional house consists of an open space and several pavilions (bale) that are arranged according to the “sanga mandala”. A typical example is shown in figure 4.

The family temple (structure A in fig. 4) will be built first. The other pavilions are placed at distances that are multiples of the main measuring unit (usually the owner’s foot length “tampak”). The multiples bear the qualities of the associated deities as indicated in figure 4 under the symbolized feet.

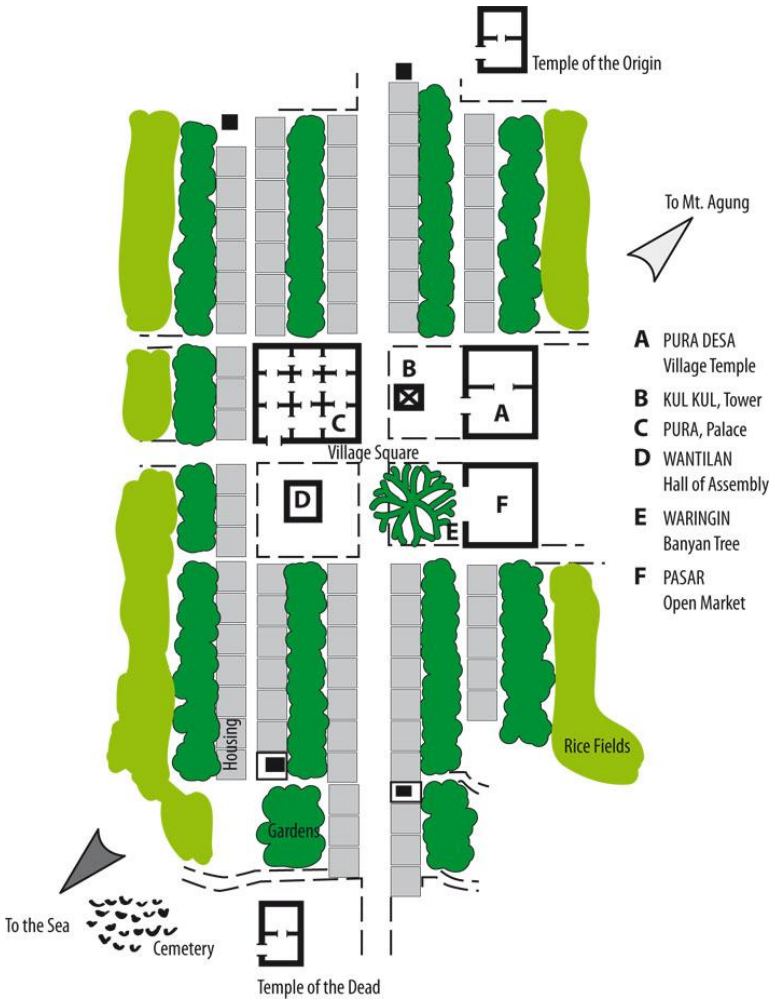

Fig. 3 – Typical settlement design, based on (BUDIHARDJO 1995).

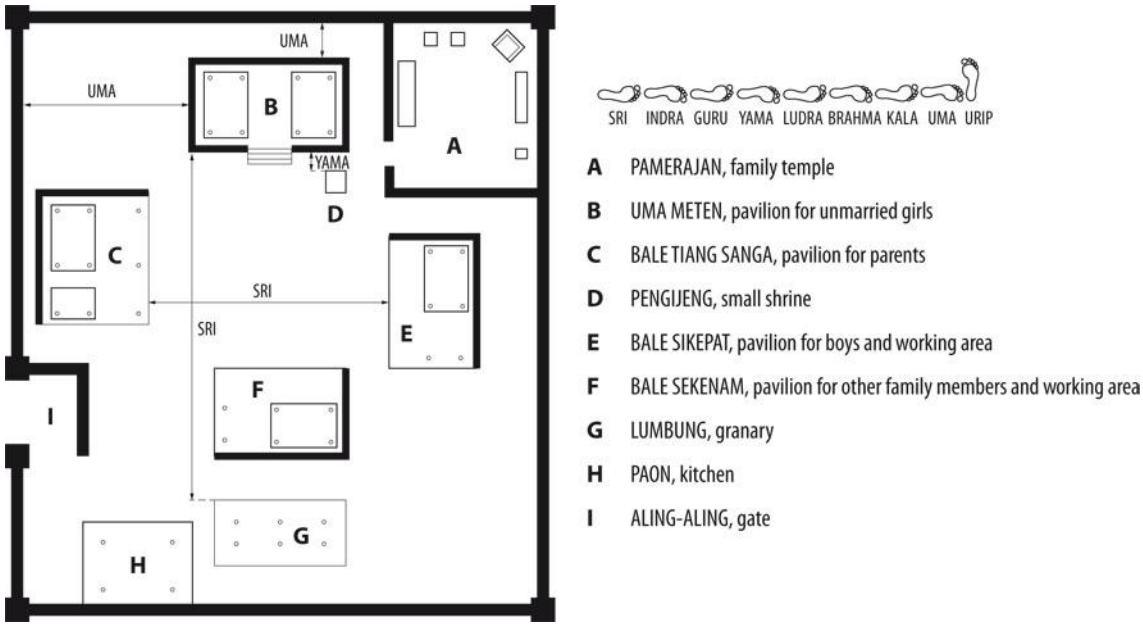

Fig. 4 – Typical house compound with distance qualities, based on (DWIJENDRA 2010).

Procedural Modelling in Architecture

"The key property of procedural generation is that it describes the entity, be it geometry, texture or effect, in terms of a sequence of generation instructions rather than as a static block of data. The instructions can then be called on when required to create instances of the asset and the description can be parameterized to allow the generation of instances with varying characteristics." (KELLY and McCABE 2006)

There are several approaches to procedural modelling in architecture. We will give a brief overview of the more common concepts.

Parametric building elements: typically common architectural object like doors, windows etc. that are used in many buildings are parameterized to cover the wide range of possible shapes. For example, typical parameters for a door are height, width, opening direction, number of wings. One example of such a system is Archicad (http://www.graphisoft.de/produkte/archicad/) together with GDL (Geometric Description Language).

CAD scripting languages: Hereby the commands of a CAD system that are usually given by a user are read from a script that controls the modelling software. Examples of this approach are VectorWorks (http://www.vectorworks.net/) or Rhino (http://www.rhino3d.com/) which both come with their own scripting language to serve that purpose (VectorScript, RhinoScript).

Visual Scripting Environments: Often this is an extension to an existing CAD package and provides a visual approach to scripting. Typically, graphical elements that represent certain functions or commands are connected by lines to indicate data flow. Examples of these systems are Rhino together with Grasshopper (http://www.grasshopper3d.com/) or Quest3D (http://quest3d.com/).

Programming environments: This approach is based on a general software development framework with specialized libraries to aid parametric design. Examples include Processing (http://processing.org/) and libraries such as anar+ (http://anar.ch).

Design Grammars: Shape or design grammars provide a formalism to create geometric shapes by a set of production rules. A production rule defines how a shape (or part thereof) can be transformed. A software package that implements this concept is the CityEngine (http://www.esri.com/software/cityengine/).

Procedural Modelling with the CityEngine

The software tool "CityEngine" is based on procedural modelling (PARISH and MÜLLER 2001) where geometry is not created all by hand, but largely through a set of rules. In the CityEngine a design grammar called CGA is employed to generate extensive 3D environments. Tools like the CityEngine allow for an efficient generation of architectural models and entire urban structures of a specific contemporary or historical style.

Typically, composition rules are derived by analysing the appearance of architectural representations from plans, drawings and photographs, which lead to formalistic design patterns. The final rule set contains a whole range of attributes which can be adjusted to appropriately set the appearance of the generated models. This "allows for the testing of several hypotheses by adjusting some of the parameters. This results in a powerful platform for archaeological discussion and exploration" (MÜLLER et al. 2006). Some examples of the use of the CityEngine can be found in (HAEGLER et al. 2009; WATSON et al. 2008), for the

reconstruction of ancient Rome (DYLLA et al. 2009), for the procedural modelling of Mayan architecture (MÜLLER et al. 2006) and for variations of the Louvre with the use of the CityEngine see (CALOGERO and ARNOLD 2011).

Reconstructing Balinese Settlements with Procedural Modelling

To appropriately formalize traditional Balinese architecture, it is necessary to take into account both, appearance and ancient building principles. These principles are adaptable to location as well as the owner (cf. section Traditional Balinese Architecture). So a parametric, rule-based approach employing a design grammar seemed well suited to aid this complex design process. We used the parametric shape grammar technique which is supported by the CityEngine to implement and visualize the digital formalisation of traditional Balinese building principles. The creation of a typical traditional settlement served as a demonstration case for this purpose.

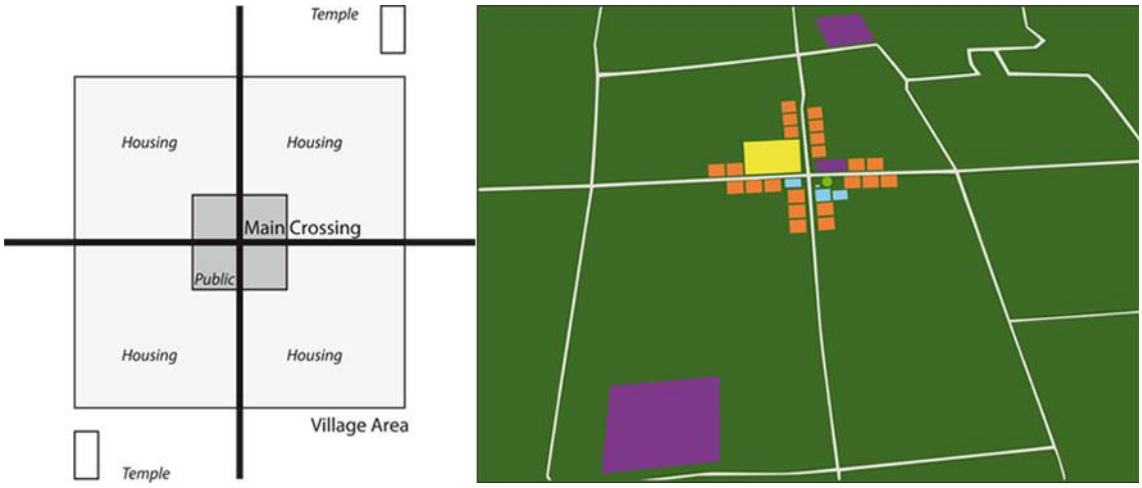

Fig. 5 – Typical village layout, schematic (left) and in the CityEngine (right).

Village Layout

In order to create a traditional Balinese village with a design grammar in the CityEngine, a street network from a Balinese village was imported from Open Street Maps (http://www.openstreetmap.org/). To this street network the typical layout of a Balinese village with coloured areas for each building type was added. The result of this process is shown in the right part of figure 5. The three temples are indicated in purple patches, house compound areas in orange. The public buildings are depicted in yellow for the palace, light green for the banyan tree, and light blue for the assembly hall, the market, the cockfighting hall and the bell tower. These diverse building areas serve as a start rule for the design grammar that was implemented. The design grammar to construct a typical village consists of a range of rules: several rules for building elements and one for each building type. To exemplify those rules, the construction of a house compound is demonstrated in detail.

House Compound

The rule for a house compound (rumah) is shown in figure 6. It starts with creating a basic layout with corner posts, the surrounding wall, placing the ground, and splitting the area into nine parts according to the building principles (1) hierarchy of space and (2) cosmological orientation. The house temple is placed in the area closest to the mountain, surrounded by its own wall with an entrance to the temple area. Then a suitable pavilion gets placed into each part of the compound and the entrance is placed at the road side closest to the sea. The creation of the respective pavilions is accomplished with a separate rule set (cf. section Pavilions below).

Applying these rules in the CityEngine to create a 3D model, results in a house compound as depicted in figure 7.

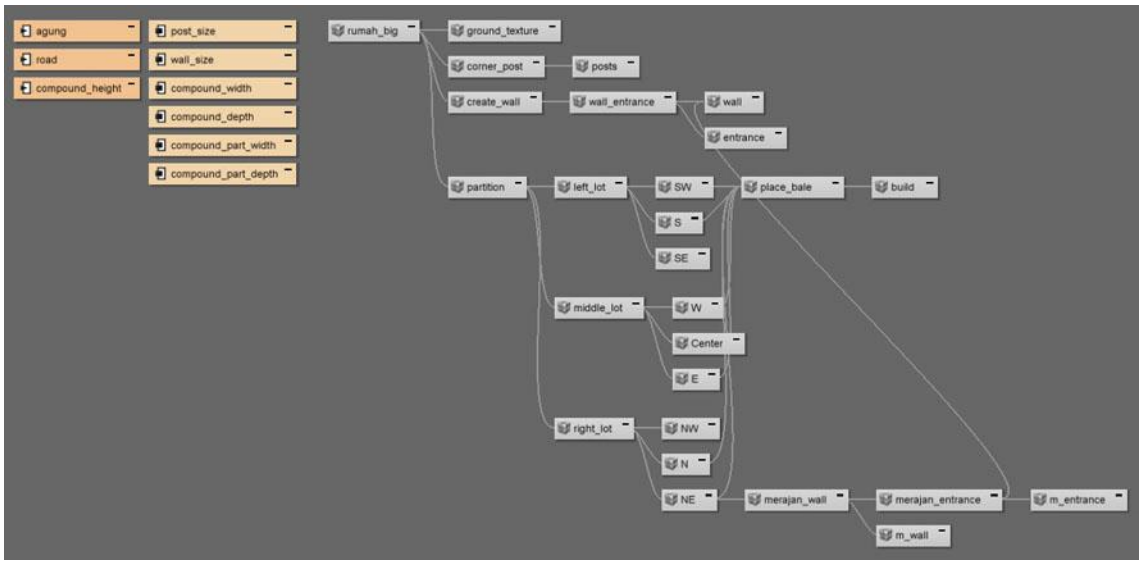

Fig. 6 – Rules for creating a typical house compound.

Fig. 7 – Traditional house created in the CityEngine according to these rules.

Pavilions (bale)

Pavilions are the main generalized form of structure within traditional Balinese architecture as most buildings consist of a collection of different types of pavilions. To demonstrate the power of rule-based model creation, different types of pavilions are created with one single rule set. Figure 8 displays a graphical overview of the rule set for the pavilion variation.

Variations for the construction of the pavilions are set to be randomly chosen at a certain percentage, e.g. the two available types of foundations are randomly chosen at 50% each, while the wooden platform will appear in 80% of the generated models. The central rule (bale) will construct the single pavilions and thereby split the structure into Base, Column and Roof.

Application of these rules in the CityEngine results in the pavilions which are depicted in figure 9 where the variation can readily be seen: The two bases in front are different from those in the back; the number of side walls varies between 0 and 2; some pavilions have a platform; there two different column bases are used.

Fig. 8 – Rule for pavilions.

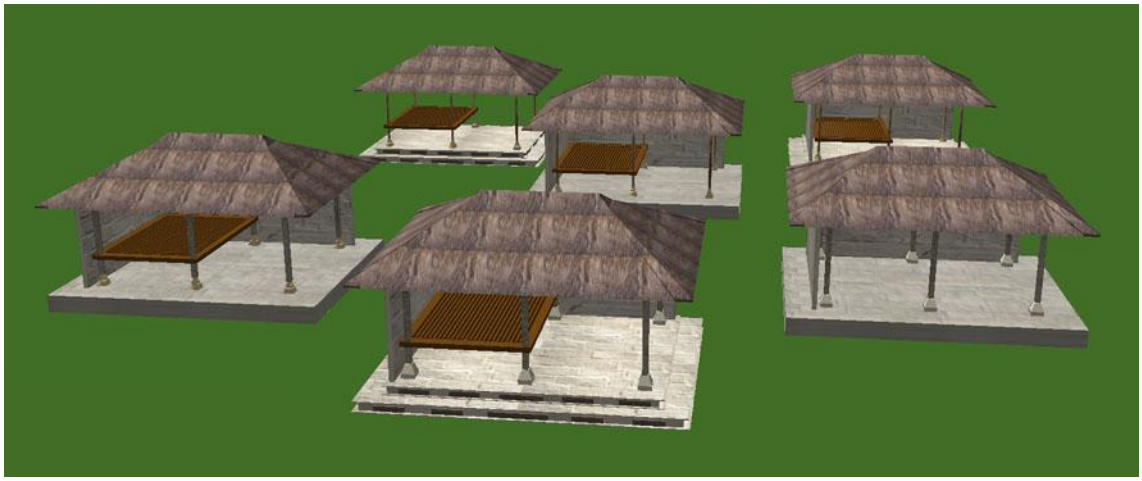

Fig. 9 – Different types of pavilions created with one parametric rule.

Village

To construct an entire village, rules for each type of building have to be developed. Putting all these rules together and applying them in the CityEngine results in the construction of the models for the village as

shown in figure 10. It provides a view at the village centre with the village temple behind the banyan tree, the palace at the upper left, the assembly hall left in front of it, the bell tower next to the banyan tree, the open ground for the market and the cockfighting hall behind it. In front there are some house compounds.

Fig. 10 – Entire village, all rules combined.

Discussion

Since the principles of traditional Balinese architecture are kept as written instructions on ancient palm leaves (lontars) it turned out that this rule-based design is very well suited to be implemented as a set of shape grammar rules as it was done with the aid of the CityEngine. Shape grammars can be defined for each structure of typical Balinese settlements (entire villages, different building types and even diverse building elements). Parameterisation of the rules also allows for the integration of human proportions (in the form of actual dimensions of the body parts of the head of a building).

Concerning the preservation of Balinese architectural heritage, the exemplified translation of the ancient lontar scripts into digital shape grammar rules might be of great value. The main drawback of this approach is the intensive initial training required to learn rule based modelling.

Future work will be addressed to additional and more detailed translations of the ancient lontar scripts. Especially the complex distance rules as applied in the layout of a house compound require a better explanation.

Additionally, a more extensive parameterisation of building rules should be formalised and implemented to account for the great variety in building styles. Beside the detailed implementation of housing structures a similar approach should be undertaken for temples and other public buildings.

The demonstrated formalization and implementation of ancient Balinese building rules so far is only a first step. Additional studies of original literature as well as on locations in Bali itself are required to achieve a deeper understanding of this topic and to better preserve these valuable rules in the age of digital information technology.

Finally, it might also be of interest to adapt the traditional set of rules to modern Balinese architecture in order to meet the contemporary needs of living.

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The city plan as an information system

The example of the Middle Islamic city of Qalhât (Oman)

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Abstract: The approach used for the making of elevations at the archaeological site of Qalhât (Oman) with the help of a DGPS and aerial photos demonstrates the efficiency of the methods and also how the archaeologist should use resulting plans as an information system. The results produce a system which takes into account the heterogeneity and the gaps of information which are inherent in archaeological data. In addition the qualification of the information obtained in the field produces a reliability map. While the geomatic tools offer flexibility for the composition of the cartography, they also offer the possibility of intuitive perspectives: they allow to capture archaeological reality of the town with the prospect of dissemination to a wider public, as well as a scientific approach.

Keywords: information system, archaeological survey, update, reliability, Qalhât.

Introduction

For ten years French archaeology has been developing the use of GIS tools, but they remain marginal. Archaeologists are familiar with data sets (JOLIVEAU 2005), being obliged to save information that tends to disappear because of human activities or are destroyed by investigations themselves (excavations). Thus archaeologists have always been producers of maps and plans. There are several possible reasons for the reluctance to use GIS tools. Procedures for obtaining plans or maps have already been in existence for a long time, and were giving satisfaction. Moreover, common logic itself leads to produce detailed inventory maps, more than thematic maps. Thus automatic mapping capabilities of GIS have not been motivating their adoption. Similarly, ways of spatial analysis initiated by geographers, taken over by English and American archaeologists in the 1970s (CLARKE 1977; HODDER et al. 1976) had only few echoes in France. Although there have been notable exceptions (VAN DER LEEUW et al. 2003), the potential of GIS for that purpose has not been fully understood.

This statement must be moderated: since the early 2000s, the community of French archaeologists using GIS has been expanding. This movement was accompanied by the creation of exchange networks, like the ISA network (Spatial Information and Archaeology, http://isa.univ-tours.fr/), which helped archaeologists to meet and share experiences (BARGE et al. 2004; RODIER 2011).

On the site of Qalhât, our work was influenced by particular conditions, which led us to develop new methods.

Qalhât is one of the most famous cities of the Middle Islamic Period, located at the tip of the Arabian Peninsula in the Sultanate of Oman (Fig. 1).

Fig. 3 – General view of the site of Qalhât.

This strategic and unavoidable place of commerce of the Hormuz kingdom during the XIII° to XVth centuries, was destroyed a first time by an earthquake in the XV° century, and a second time by the Portuguese in the beginning of the XVI° century (ROUGEULLE 2010). To study and develop this part of their national heritage the Omani authorities decided in 2008 to entrust Axelle Rougeulle, from the French CNRS (UMR 8167) for the first exploration of the town.

Extending over a surface of 35 hectares, the site is located at the foot of high mountains, in front of the Indian Ocean. In addition to these natural protections, it is surrounded by large fortifications, protecting the city and its port. A. Rougeulle opened several excavation fields, which brought answers to questions of chronology, material culture and trade networks. The building of a GIS was also one of the main objects of the project but the large size of the site and the difficulties of ruins interpretation forbid to use traditional methods of mapping for studying the urbanism network of Qalhât.

To map the city including topographic data and a drawing of each building, we used a composite method based on the use of aerial photographs and Differential GPS. Especially, the map was considered mainly as an Information System, structured in a GIS. The main principle was to gather raw data in the field, and from them to construct a model able to evolve according to the advances of research. Conceived in that way, the information system not only allows to generate several types of cartographic representations of the site, but also enables evaluation of the reliability of raw data and provide transparent interpretations.

Acquisition methods

A Differential GPS was used to determine the layout of visible structures. This was easy in sectors of low concentration. However, in the central quarters of the city, remains were too entangled, and looked just like huge humps of stones (Fig. 2). But often, what seems incomprehensible seen on the ground appears more clearly seen from the sky.

For this reason a camera carried aloft by a kite was used, operating by remote control to take aerial pictures (SANZ and BARGE 2005). Markers were set on the ground, easily visible on pictures, for enabling geo-referencing. Through photo-interpretation, we were able to outline visible buildings, although sometimes only

roughly. In a second time we verified these determinations on the ground. In many cases, elements that were not linked on the ground appeared to be parts of similar structures when mapping with GPS (Fig. 3).

Fig. 2 – Left: View from ground level of the city center. Right: aerial photography showing two kinds of building's organisation: on the left, with loose planning, on the right, densely built (city center).

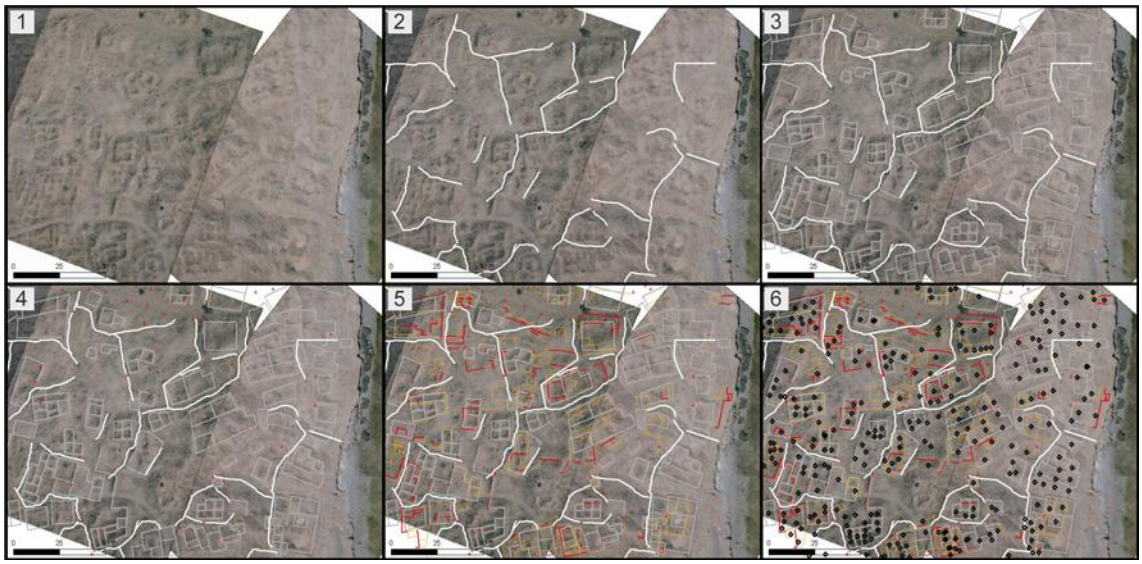

Fig. 3 – Work on city center step by step: first, aerial kite view, geo-referenced. 2, with DGPS, street recording. 3, the visible structures on the picture are digitalized. 4 and 5: back on field, control points, validation or correction of each structure's map. 6: taking points "id_space" in each space delineated.

This composite method enabled the city map to be completed step by step. In comparison with the use of a tachometer, that is traditionally employed, aerial photographs allow to progress from general network analysis to particular spacing identification. Then GPS allows a geographic representation of these interpreted remains. It has the advantage of being coupled with a field notebook where a description of each element can be recorded (for example the width of a wall and the size of its stones, Fig. 4). Indications that add to the reliability of the element and that can be mapped.

The use of a field notebook allows the map to be instantaneously drawn in the field following the process of seeing and describing structures, a valuable aid that cancels the necessity of a preliminary sketch.

Moreover, traditional method of archaeological mapping saw the plan as a drawing. There was a single reading of the terrain, given as exact, and this reading was frozen in the result. Here instead, we generate a

raw data set from which it is possible to create several interpretative maps leading to in a living information system.

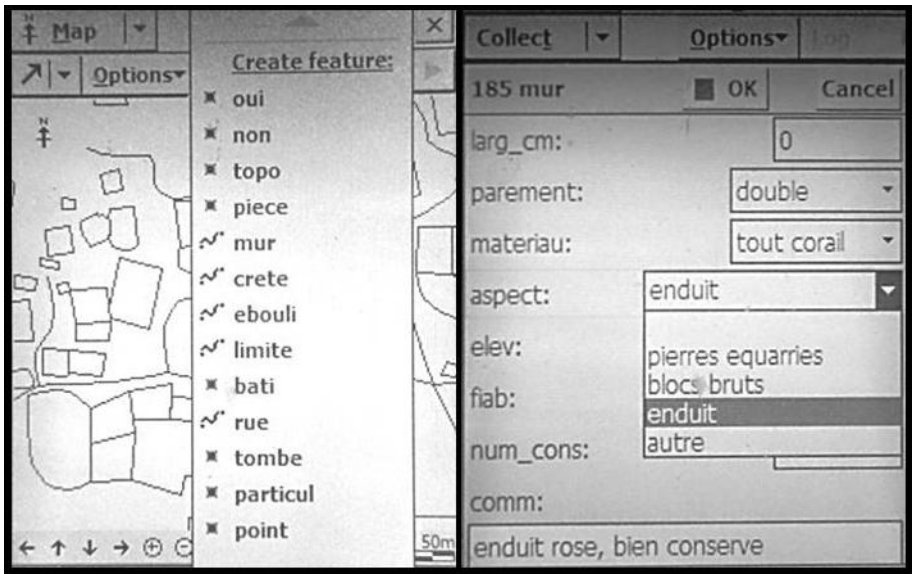

Fig. 4 – Field notebook on the Trimble DGPS: each entity is described inside a data dictionary before designated.

Data structuration

On the field, with the GPS, walls and edges were recorded to enable delineation of buildings. Edges are suggested by indications such as a break in the slope or a change in the texture of the soil. These traces are not necessarily joined. A point “id_space” taken in the centre of the outlined space enables recording of the type of space and its height in relation with the whole building.

Besides, traces seen in the aerial photos, once validated, are assigned to a feature class, called “bld_pict”. Again, a point “id_space”in the center of each outlined space will be taken to record information about it.

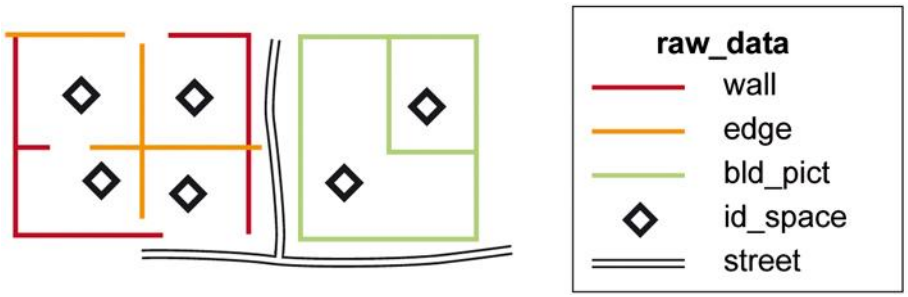

Fig. 5 – Data structuration: a first DDB contains exclusively the raw datas.

All these elements are assigned to a feature dataset called “raw data” (Fig. 5). These are crude field data, which will not be modified. They will be used to feed other feature classes called “spaces” which belong to a feature dataset called “model”: the latter can evolve. It will enable the outline of polygons that are integrated with their attribute data of the identifier “id_space” (Fig. 6).

Several contiguous spaces form a building to which a number is assigned. Terraces are particular spaces that may be situated within a building (they are private) or outside a building, (where they are public). These terraces play a large part in city spaces; they often were built to adapt to natural relief. The adjoining of these polygons is perfectly respected in a topology (streets for example which are connected in a network).

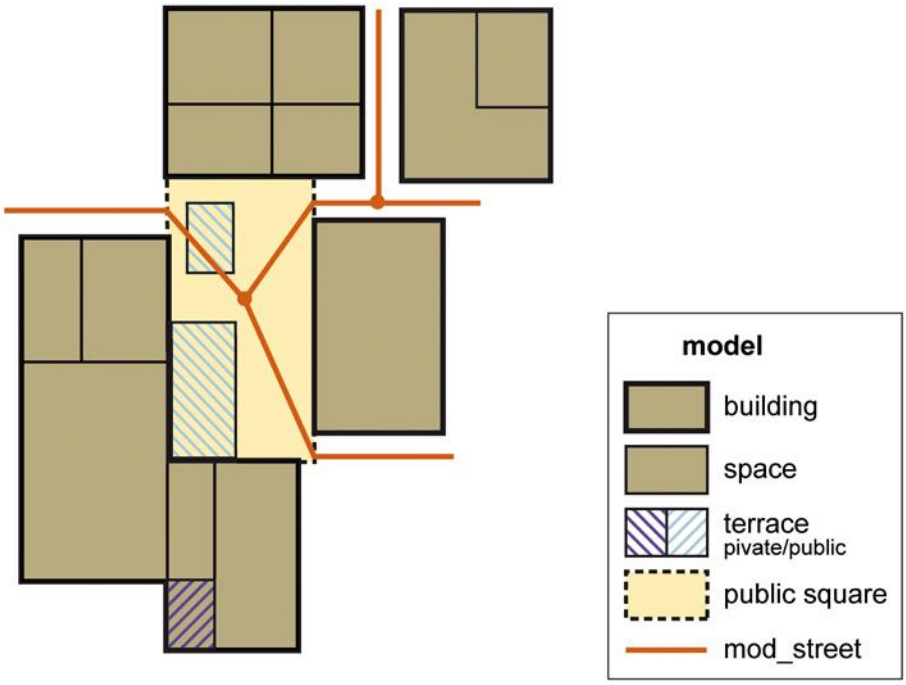

Fig. 6 – Data structuration: the second DDB outcome from de field datas is an interpretation.

Map and its reliability

The information system structured in this way enables production of a city map, first according to the canons of archaeological plan. But the functionalities of symbol tools also enable production of other representations: the type of spaces identified in the field, or the functions determined by the archaeologist (Fig. 8).

The information system also allows for an estimation of the reliability of the plan. We have seen that some areas are simple and clear, whereas others are complex and hardly read. We have also used different feature classes, which reflect a reality that is well known, that is sometimes only probable, or that is even sometimes only “possible”.

There are two types of lines picked up with the GPS to define the buildings: walls and edges, the latter being less reliable.

There are also edges drawn on the basis of aerial photos, verified on the ground. For these, three levels of validity could be distinguished. In level 3, the geo-referencing of the photos is satisfactory and the traces are coherent with observation on the ground, giving a comparable reliability to that of “walls”. In level 2, traces visible on aerial views are less easy to be read on the field. The level of reliability matches that of “edges”. In level 1, traces could not be clearly verified, mainly because of the difficulty of reading the vestiges on the ground.

Thus from the point of view of reliability, a correspondence between the two types of lines (“walls” and “edges”) can be established, with 3 levels of reliability (3, 2 and 1).

A regular grid measuring 20 m per cell is then applied to the map. In each square, the accumulated length of the three types of traces is calculated, and the percentage of each type in each square is established. This enables sorting of the squares:

- ► Those in which level 1 traces are predominant,
- ► Those in which level 2 traces are predominant,
- ► Those in which level 3 traces are predominant,
- ► Those that contain only level 3 traces.

In this way a scale of increasing reliability based on 4 levels can be obtained and mapped (Fig. 7).

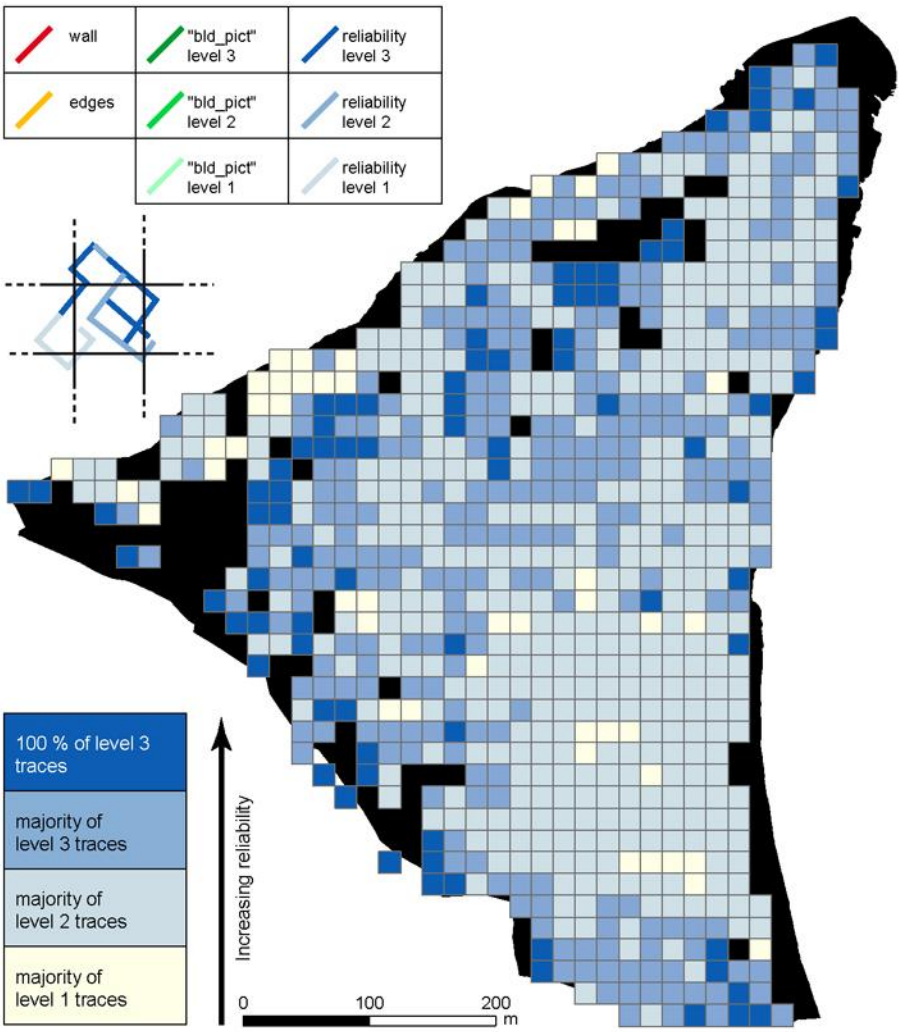

Fig. 7 – Reliability of the raw datas.

The result corresponds well to the complexity of the terrain in that it can be understood intuitively.

This map enables the archaeologist to know the level of reliability he can attribute to the plan according to the sector being investigated.

Information system and its uses

The information system can also be used in other ways: without being a GIS specialist, the archaeologist can undertake an exploratory approach to the data by activating the display functions.
In this way, it is possible to develop the plan (Fig. 8).

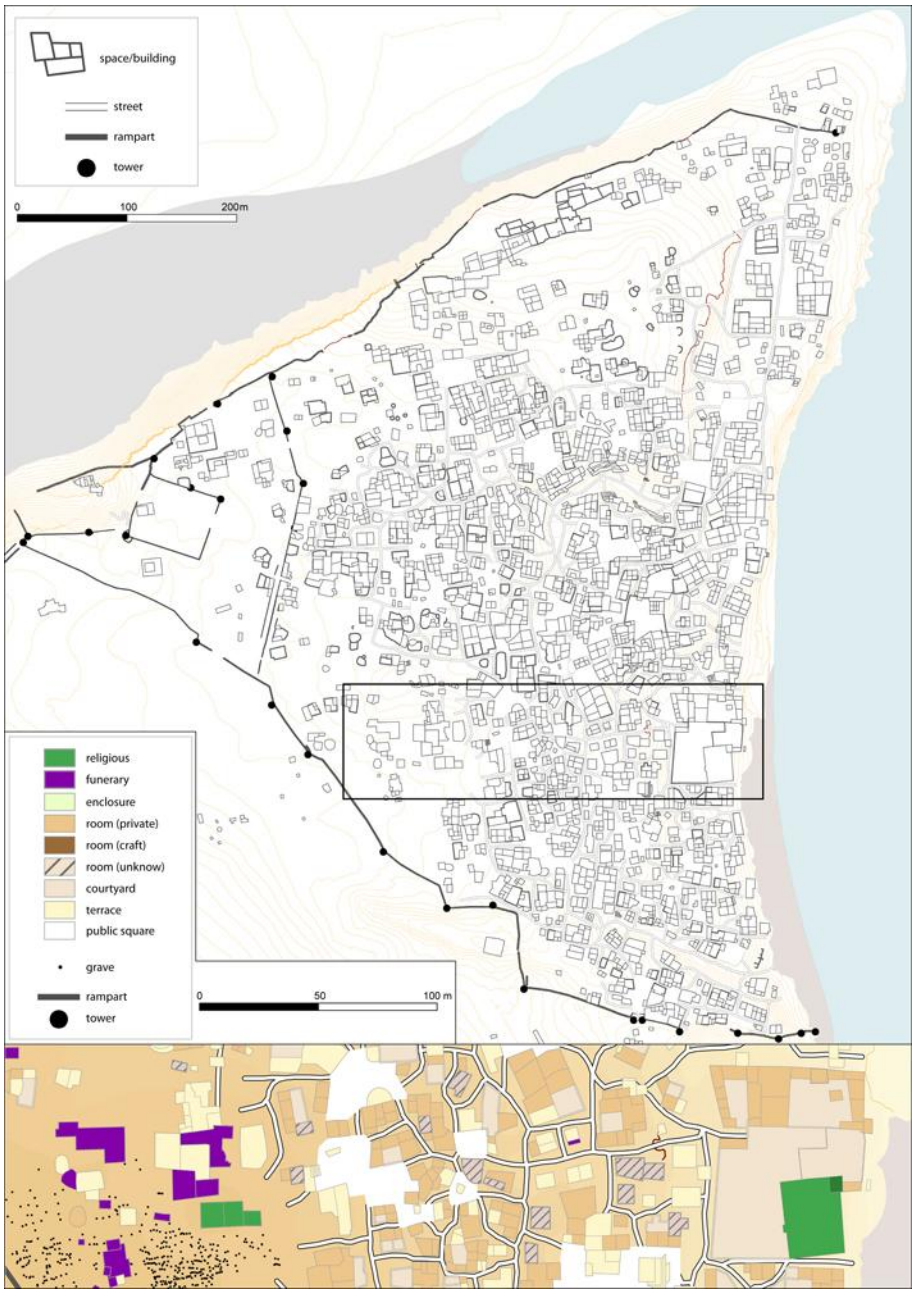

Fig. 8 – Map of the medieval city of Qalhât. Different possibilities of representations.

In fact, the structures depicted on the plan are open to interpretation. They apply during the choice of the different traces of the layout, such as their continuation, to constitute the spaces of the model. It is always possible to superimpose the traces of the depicted layout and the model, and then to modify the latter according to a new interpretation considered to be more pertinent.

Interpretation also applies in the field. In this case, there is no longer recourse to the elements that led to the choices made; however, the attribute data recorded on the ground can be displayed when the recorded traces are doubtful (Fig. 9). In the same way, it is possible to modify or refine the plan, based on work carried out on a finer scale - excavation plans or plans of the buildings studied.

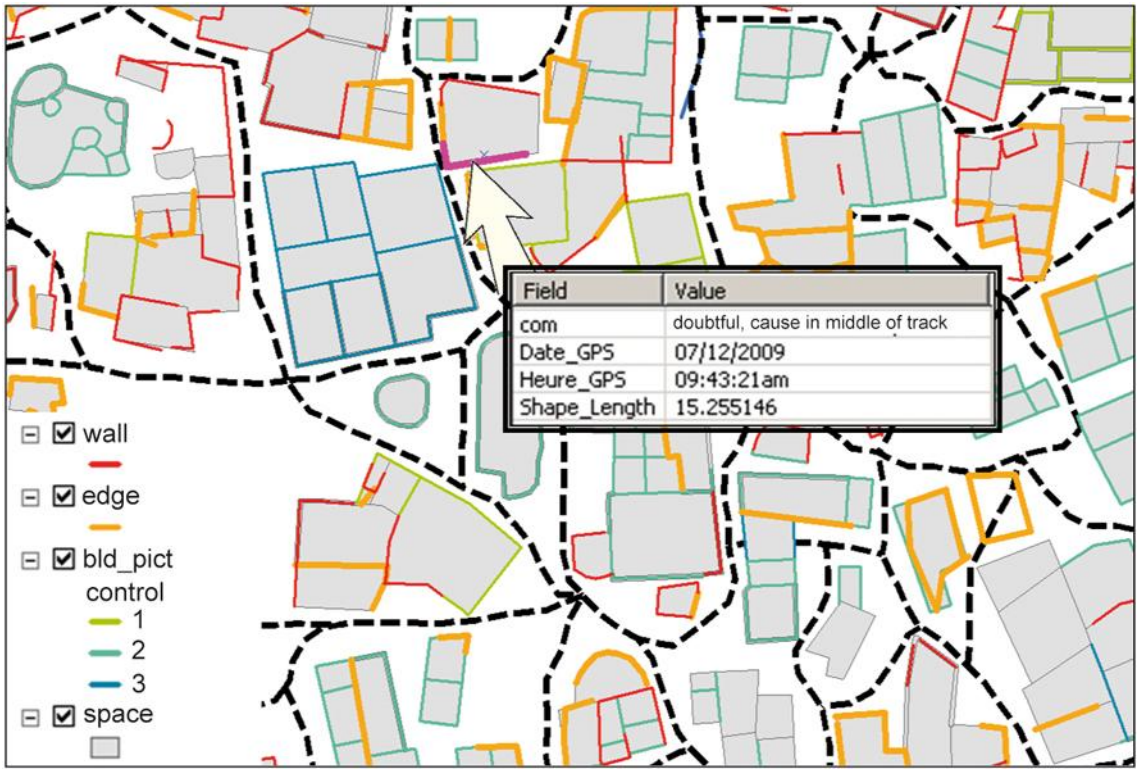

Fig. 9 – Building the model, it’s possible to go back to the survey conditions.

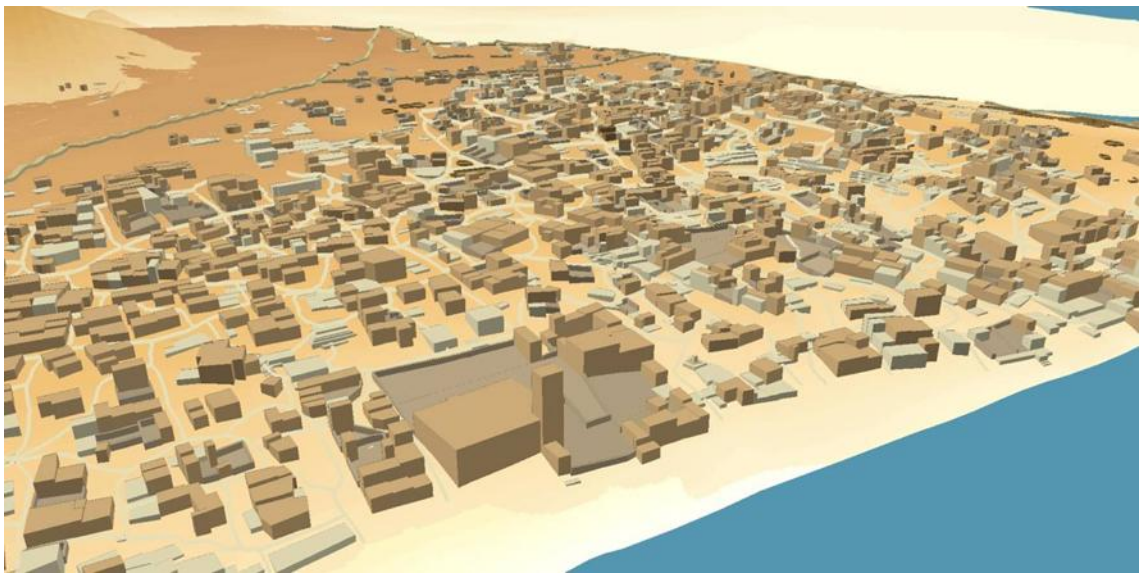

Fig. 10 – Percepective views are easy to produce with the GIS tools.

Fig. 11 – Two sights from Qalhât: with kite aerial photography, and perspective view from GIS model. This type of layout is very meaningful for large public.

The information system also enables proposition of 3D representations of the site. As we have roughly recorded on the ground, the relative height of each outlined space – 0 for the open spaces, 1 for the spaces whose cover of collapsed debris indicate a closed structure, 2 when the collapsed debris reaches a height indicating the existence of several storeys –, this height can be expressed by extruding volumes based on polygons. Images of the site can thus be obtained, quite rough graphically, but enough for a not specialist to have an idea of the medieval city (Fig. 10, Fig. 11). Indeed, it is not easy for a visitor to see any representation based on a field of ruins. Those views propose a representation that agrees with the information system, and thus with the state of the research (Fig. 12).

But these 3D representations go beyond being just useful for communication with the public. They can be used to back up scientific discussion, or even to stimulate constructive criticism; this enables understanding of the archaeological realities from an angle that is closer to intuitive perception. The hypothesis is that the 3D representations are perceived more rapidly and that they illustrate more concretely the urban plan reconstructed by the field work; thus they enable scientific discussion to be supported by evidence that is more easily perceptible, even dynamic, whereas the reading of a plan, even for an archaeologist, remains a technical approach and involves an abstract perception of the city.

In this scientific framework, as many views as models may be proposed, scenarios may be built and hypotheses put forward.

It's the same way for the updates of the data according to the advance of the knowledge of the site. So, it is easy to integrate the new plans of excavations which sometimes modify determinedly the aspect of buildings

such as they had been perceived the first time. These data are added in the raw data of ground, and allow the elaboration of new models. Thus the transparency of the elaboration of the new plan from the raw data is always preserved.

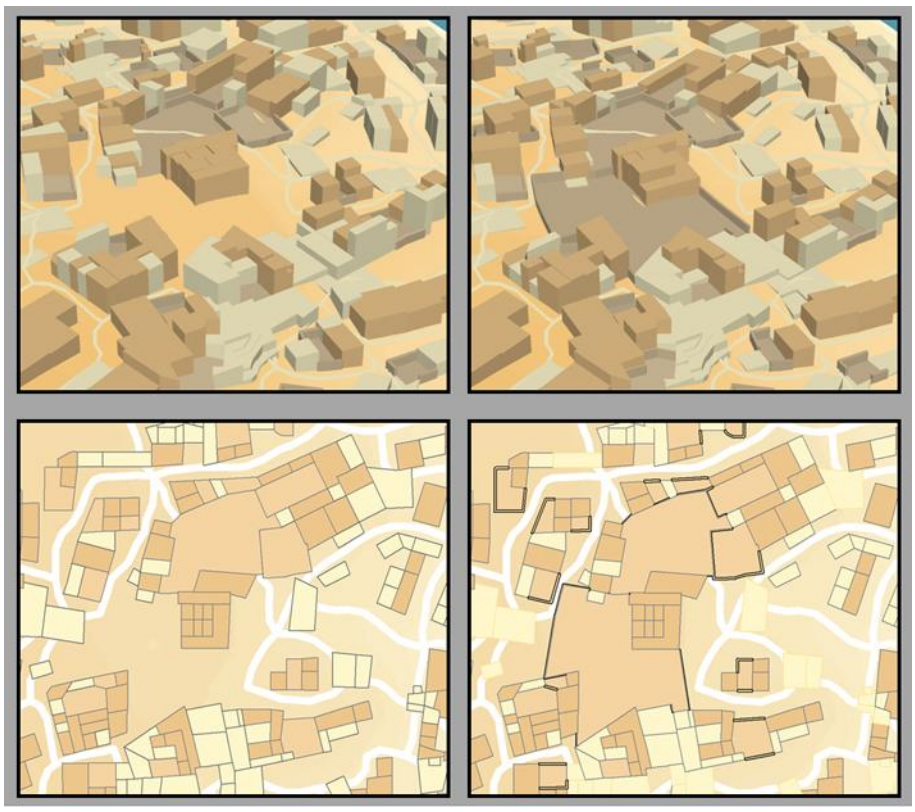

Fig. 12 – With excavations, the knowledge of the site refines: a new model is easily generated.

Conclusion

The survey method followed in Qalhât presents several significant advantages for archaeology.

The first of these advantages is the implementation of smaller time frames, thus reducing the cost of prospections. For instance, here, five weeks were enough to cover the site and its surroundings (about 60 ha). Moreover, apart from the Differential GPS, it requires a very inexpensive hardware for its implementation.

The second is to offer a new approach to the survey methods traditionally used in archaeology, at almost any scale. The whole point is to design from the outset the plan as an Information System structured in a GIS. Thus, several city map can actually be built, but this approach leads to a living tool that opens up to other types of uses. According to us, the interpretation of raw data transparent, unlike the implicit production plans, constitutes a great advance scientifically speaking. Finally, the updating and refining knowledge can always be included in the database and are, for archaeologists, a valuable support for reflection and sharing the progress of their work.

The potential use of this information system can be evaluated in the long term. Indeed, besides being a tool to the archaeologist, it has a place in the development of the site: this is a complete map database, useful for example in terms of tourism development plan of the site, in direct connection with the Omani authorities. It

can also be used to produce images for explanatory scientific popularization: thematic plans, views and even videos bridleways.

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The interpretation of archaeological persistence to generate digital 3D architectural typologies

The case of *ksar* Tatiouine in the Moroccan High Atlas

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Abstract: We are convinced about the need to investigate and to document this sustainable architecture used as the traditional habitat and, at the same time, characterized as a high value Heritage. Until now the subject was not studied and analyzed with the proper attention. For this reason, we have surveyed and represented, taking the architectural drawing as the first tool, the earth constructions of the Outat Valley in Midelt (Morocco). This work allowed us to perform comparative analysis about dimensions, constructive techniques and formal features; the main outcome has been the “key” for the interpretation both of the general design process and the reasons of details otherwise unnoticed. The situation of these small cities built in earth, mostly converted back to earth due to natural deterioration; often doesn’t let us know the original typological models and their subsequent evolution.

With the main objective to get an urban reconstruction of this evolutionary process, we have developed 3D models of the existing archaeological persistence taking as example the *ksar* Tatiouine. The synthetic analysis of these models has led us to create completed volumes to show a full three-dimensional simulation of the *ksar* and its constructive evolution.

Usually we refer to the two-dimensional analysis for the study of architectural types originated by archaeology. In this case, the two-dimensional analysis of the design is based on the conversion into three-dimensional models; a further treatment of the model is its texturing with the use of realistic lighting and high quality images, this processing, combined with the actual imaging solutions allows to read pathologies and structural phenomena in act in these buildings with a more versatile tool at our disposal to face the preservation of structures in risk of disappearing.

Keywords: Earth architecture, urban archeology, architectural typology, 3D modeling.

Introduction

In the High Atlas Mountains in Morocco there are small towns made of earth still preserved that in the last years are gradually disappearing while their residents migrate to modern cities, and in the many cases, to Europe. This valuable heritage at risk has been the subject of our research over the past three years. Here we present a paper in which we describe the methodology adopted for the 3D simulations of archaeological remains with the aim to improve their analysis and make assumptions on original conformation and their evolution.

This research was begun years ago through a PhD Thesis (RODRIGUEZ-NAVARRO 2008–2009) on the Muslin earthen architecture for defense that is present in the Valencian Territory and that formed part of a

wider investigation field that keeps in contact many different countries of the Mediterranean Basin, from east to west.

The present study makes part of I + D project (Investigacion+desarrollo), *Arquitectura habitacional de tierra en el Alto Atlas septentrional. Midelt (Marruecos)* (20110499 Cód. ADSIDEO-2011 y NR 1926 PAID-06-11-2011) funded by the Universitat Politècnica de València (Spain).

Fig. 4 – Outat river valley in the High Atlas Mountains (Copyright: Montserrat Simón).

Fig. 2 – Jaima tent close to the Outat valley (Copyright: Teresa Gil).

Geographical setting and architecture

Several mountain ranges cross the country: The Rif, the Middle Atlas, the High Atlas and the Anti Atlas. The High Atlas can be crossed by the Atlantic coast or by a natural pass that takes us directly to the pre-Saharan valleys of the south. The studied area is located in the northern part of the range, along with the natural passage, specifically at the foot of Jbel Ayachi, the highest mountain in the east with 3.737 meters of

altitude. From this summit to the city of Midelt, there are series of *ksour* (fortified towns made with earth; is the plural of *ksar*) that have been the subject of our research.

These cities are the product of a sedentarization process that led nomads to group together for improving their safety. The various Berber tribes have always been showing their rivalries, so they made this typology of fortified cities like a common model for any settlement.

They all can be found on the river banks, in order to easily provide water for life and agriculture. In this sense the study area has been the Valley of the Outat River; around it are different *ksour*, from *ksar* Tatiouine to *Ksar* of Atmane ou Moussa, near the city of Midelt. In this city, founded by the French at the beginning of their protectorate, there were others *ksour* that were absorbed or demolished by the very growth of the new city.

The materials of construction and ongoing maintenance requirements

The materials used for the realization of these buildings are available on site, i.e., earth, water and wood; at them it is possible to add straw and esparto. With these materials they use construction techniques from the Pre-Saharan valleys, that is, techniques from another geographic location, with a completely different weather conditions. However, it is easy to see how these nomads coming from the south have brought their constructive techniques and have how directly they implemented them in a so different place. They were coming from dry places with little rainfall and high temperatures, once arrived in the Outat Valley their constructive legacy was subjected to much lower temperatures, strong seasonal rains and even heavy snow in winter. Those problems have generated the necessity for these small cities of earth with flat roofs to be undergone to a comprehensive annual maintenance to have guaranteed structural stability and comfort.

Fig. 3 – *Ksar* Tissouit Sidi Hamza in the winter. We can see the snow in the mountains and the Outat river on the right.

Last few years, especially the last decade, we are seeing a generalized depopulation of these *ksour*. The arrival of electricity to many of them, joined to television news (they were not prepared to see everything), and the apparent success of those who have managed to migrate to big cities and ultimately to Europe, make that any inhabitant aspires to leave this magnificent place. So, slowly but inexorably, the *ksour* of Outat Valley are depopulating, or in the best cases, the people just makes new houses with construction systems that clash with the existing tradition and with the culture of the place. Immediately following the abandonment begins the process of deterioration. The lack of maintenance in a few months makes devastating effects, and in a few years the general collapse. The same collapse of the abandoned house that does not endanger other neighboring, creating a chain of abandonment.

As mentioned last *ksar* on the climb up of Jbel Ayachi is called Tatiouine. In 2008 we first visited it, took some pictures, sketches and notes on shape and conditions of that *ksar*. They had no electricity or water or any other service of infrastructure, and was partially occupied. The part closest to the river was the one in worst conditions if compared to other parts, being collapsed more than 80% of it. In the course of these years we have seen, in addiction to the advent of electricity, the sorrowful falling of many of the abandoned buildings. In fact, each year we observed that the *ksar* progressively disappears, with the conviction that in few years will be no traces of what it was one of the biggest settlements in the valley. In order to document the site, that we can define as archaeological although still used by almost 20 families, we began the survey of all buildings with different integrated techniques. We incorporated the topographic survey for providing a accurate reference system to other survey techniques such as traditional methods and photogrammetric survey for the *ksar*'s documentation, in particular of those fallen parts now layed on a slope.

The archaeological analysis and existing patterns

Thanks to the first planimetric analysis we deduced how *ksar* Tatiouine really should have begun: with a smaller *ksar* corresponding to the part closer to the river. This area, the most deteriorated, is known to the locals as *Igrem Akadim* that means "old city". Then, as we go up the valley, we found an area with no buildings, as a square, where are the mosque and the hammam (baths). On the other hand, while we were carrying on the survey, it appeared another part more firm, stable, forming a regular pattern offset from the previous boundary of the *ksar*, we can deduce that this is a posterior construction, and then it was built a wall connecting the two *ksour*. Inside that void space it was built the mosque and the hammam in the between them.

The main aspects of the methodology we developed for this research is the comparison between the remains of the *ksar* we are investigating and other similar examples of the same zone. Due to the worrying lack of means of Tatiouine population, the state of conservation of the buildings is highly deteriorated, so it was necessary to gather information from other construction with the aim to develop a plausible interpretation of the ancient shape of this complex.

In the same valley are present other important remains as the case of a big and more firm *ksar* that still provide data about the architectural features of towers and the external finishing of rammed earth walls.

In the case of the Smoura *ksar* it is still possible to appreciate lots of details both for the superficial finishing so as decoration elements that in the case of Tatiouine has been erased by the persistence seasonal rain

and snow. The progressive dissolve of constructive elements could not be contained by means of the common maintenance practice because the present dwellers of these sites haven't any particular constructive skill and have never been trained in rammed earth technique, as I said before.

Fig. 4 – Tower in a corner of *ksar* Iguerouane where shows the top decoration.

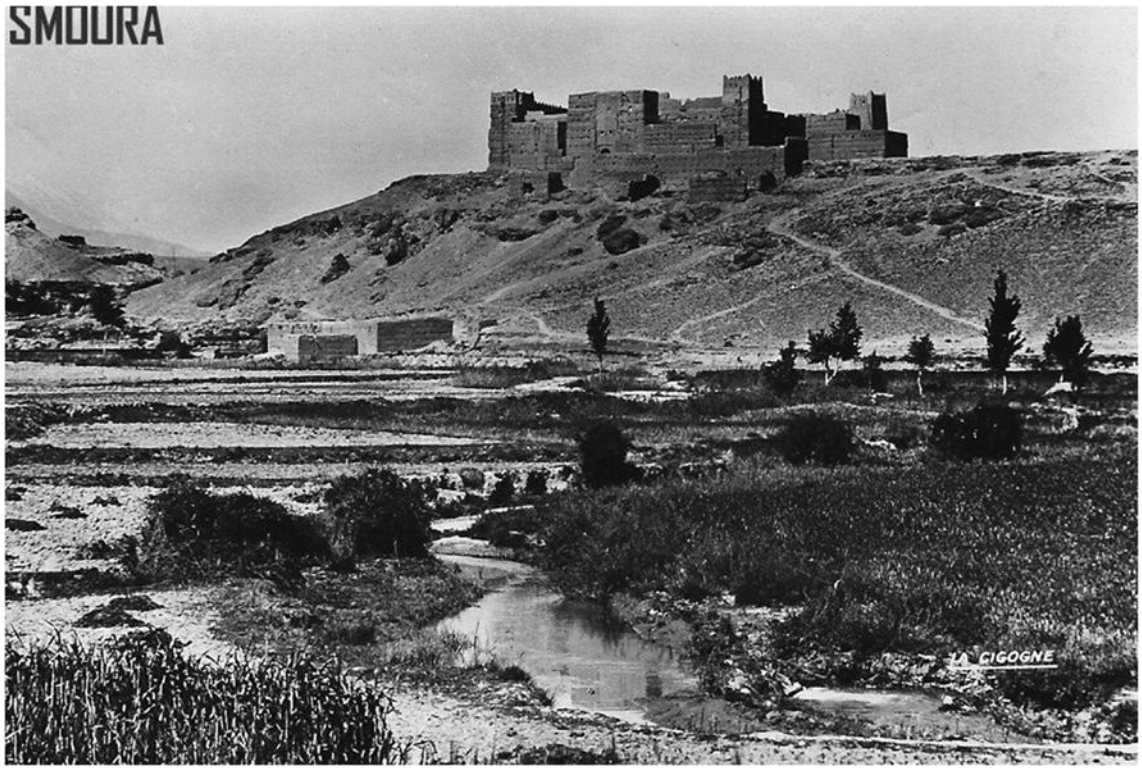

Fig. 5 – *Ksar* Samoura at the beginning of twentieth century.

On the other hand, the external appearance is not the only theme we are interested in, because once surveyed the Tatiouine remains it clearly came out the importance of the ancient internal arrangement of the *ksar* (functions, distribution, recurring technical solutions, etc.) so as the constructive phases.
By a side there is the problem of the building’s “surface”, its external shape, in other terms its ancient appearance; by the other there is the understanding of how interiors were arranged inside the general organic structure of the *ksar*.
Some *ksour*, like Smoura, Iguerouane, Asakka and Tabenatout provided possible solutions for the upper part, made of adobe, of the typical square towers, that constitute the corners of the *ksar*. We gathered lots of information by visiting the mentioned sites, taking pictures and sketches, interviewing local population and obviously collecting old drawing, reports and photos from the first explorers that witnessed the Tatiouine state during the XIX century.
As mentioned before the Smoura *ksar* is an interesting case because there is still visible the presence of the typical spikes crowning the upper part of the towers: in the old pictures it is even more clear the kind of decoration we have were interested in for the development of the 3D reconstruction.
It also came out other decorations, not visible in ancient pictures, but still present in some ksur of the valley: we are referring to addiction another invariant of the architectural decoration that appears below the spikes: the typical four holes below each triangular spike. These holes are carved decorations located on the external surface of towers and portals. Three of the four holes have a square shape but the lower one is rectangular and taller. Every tower has in general a quadrilateral shape, with every side characterized by the same measure. The triangular spikes are bigger in the corners.
The first constructive phase of a *ksar* is the product of the physical union, made by rammed earth walls, of four towers in the corner of a square; at the centre of one of these walls we have a portal, highlighted in different ways, but in general identified by one or two towers such the ones in the corners.
The inner spatial organization inside the system defined by the towers and the walls it is ordered by using simple orthogonal patterns: the first habitations that are constructed are those placed inside the *ksar* along the external walls. Starting from the main portal is the main street of the *ksar* that follows the orthogonal orientation of the outer walls. Sometimes the street splits in two new streets defined by the boundaries constituted by the house walls. In general when a street makes an orthogonal angle or a crossing there is a void space up on it that goes from the soil to the roof allowing natural illumination.
Thanks to a complete topographic survey of the Tatiouine *ksar* it was possible to detect constructive phases so as the possible internal distribution made of streets and dwellings that we used for the development of the 3D digital model for the reconstruction.

Approach to the development of the 3D reconstruction hypothesis

Once gathered alpha-numeric and graphic information (surveys, photos, etc.) it was possible to guess a probable shape of the different constructive phases of *ksar* Tatiouine.
The first step was the development of a 3D model of the current condition of the *ksar*; it was used a mesh modelling program with the aim to build a low resolution model of the different cells forming the whole Tatiouine complex and a partial DTM (digital terrain model) of the environment.

Fig. 6 – Topographical survey for planimetry. *Ksar* Tatiouine.

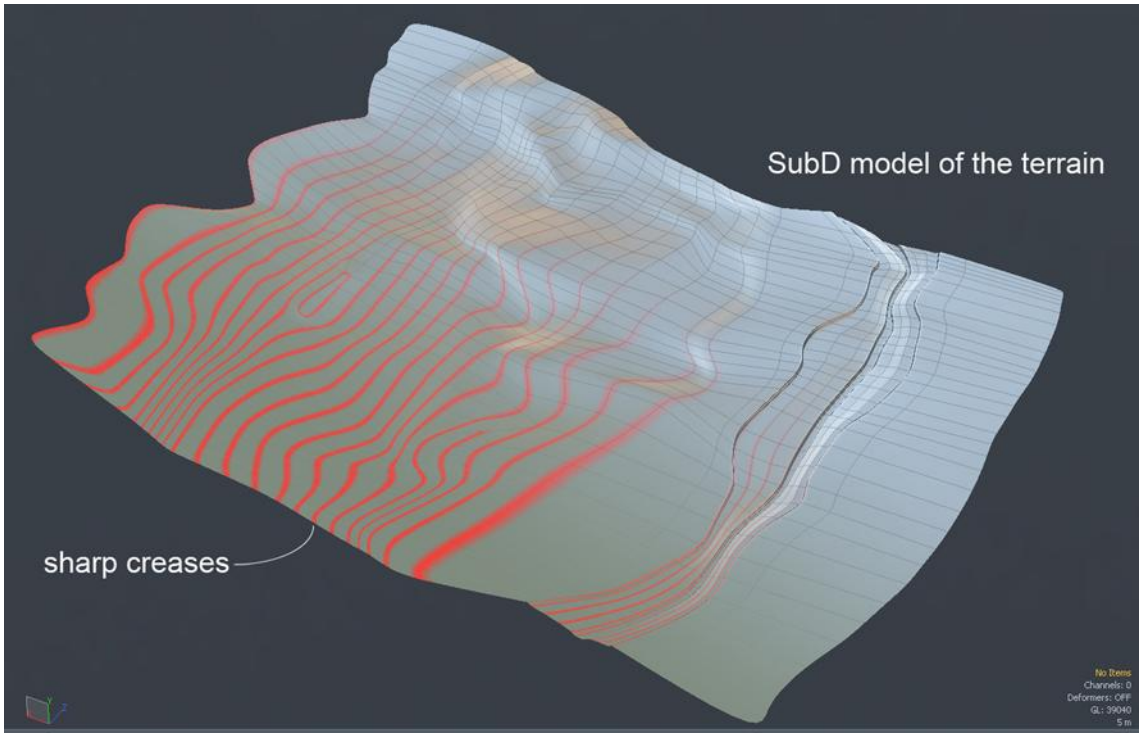

Fig. 7 – Subduivision surface model of the terrain: thanks to edge weighing tools it is possible to obtain a smooth DTM that correctly fits with the spline curves from the topographic survey (Copyright: F. Fantini & T. Gil).

Once imported the topographic survey inside the 3D program as classic CAD polilines (remains and contour lines of the terrain) they were used as 2D template for the next phases consisting in the creation of the DTM, and then of the walls. We decided to use exclusively quadrilateral polygons with the aim to use the polygonal model as the control mesh of a subdivision surface model (subD). A subD model is a mathematical representation of an object that has the capability to increase and decrease the number of polygons used by the render engine to calculate still images or frames of an animation. Due to its nature of reconstructive representation we opted for a technique known as box-modeling for carrying out the walls, the towers and roofs of the *ksar* that should be seen from far once matched the 3D model with the photos of the valley in the current state.

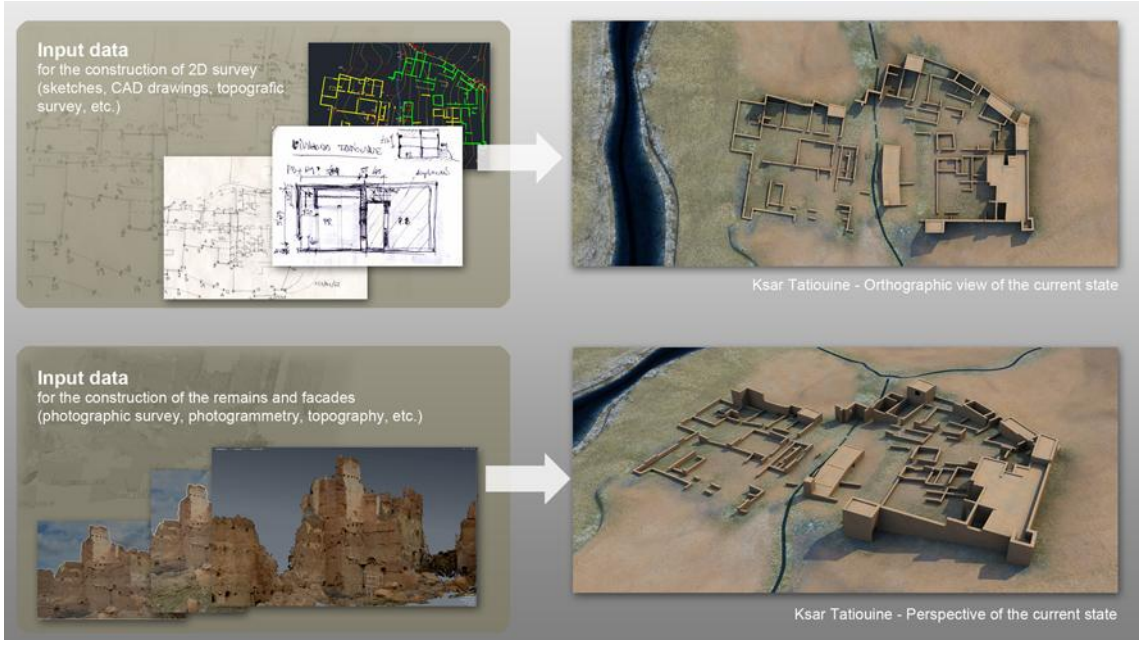

Fig. 8 – The process of *ksar* Tatiouine 3D digital model: input and outputs.

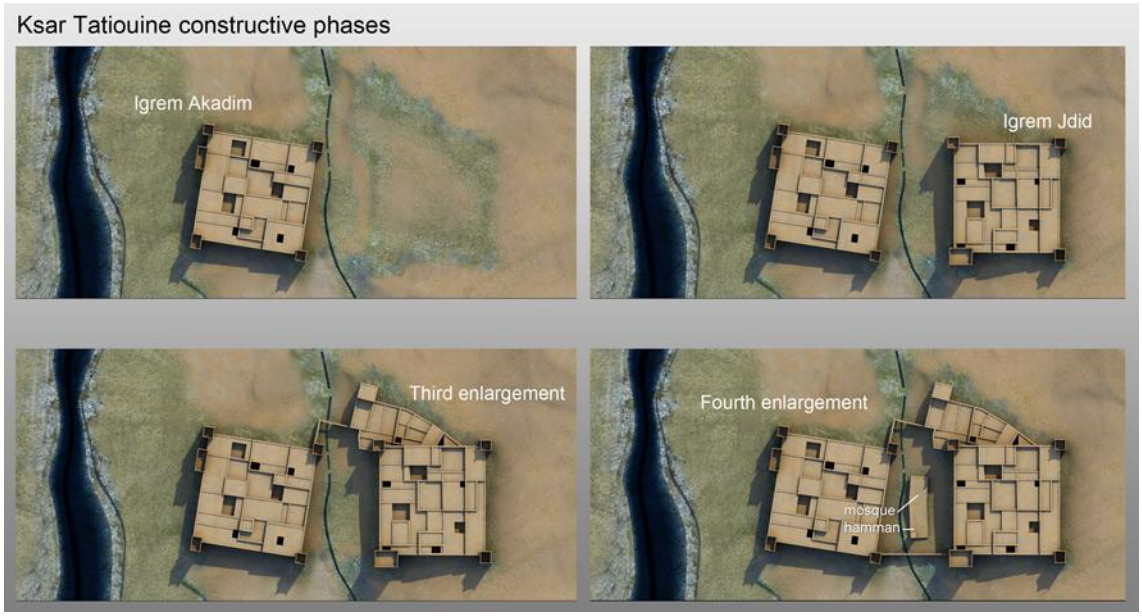

Fig. 9 – Evolution process of the *ksar* Tatiouine.

The terrain was generated using the technique known as “spider net” (FANTINI 2009) consisting in creating a first opened (or closed) loop of quadrilateral polygons whose edges are progressively extended and conformed to the pattern defined by contour lines. The modelling software we used has implemented since its first version a very powerful tool for edge creasing that allowed us to create a very accurate representation of the original contour lines from topographic survey, avoiding the common problem of subD that in general cannot provide an accurate fitting with the template curves due to the approximate algorithm used for their subdivision process[17] (FANTINI 2007).

[17] In this case we used a subD typology called Catmull-Clark extended.

We decided to reconstruct the external aspect of the *ksar*, beginning with the *Igrem Akadim*, taking in consideration the typological reading made on the existing walls that led us to understand the position of the ancient streets so as the pits for the lighting them. Typology also provided us the capability for guessing the positions of the terraces on the roofs. Due to the terrain slope the *ksar* external walls fallow the same inclination by means of little steps depending to the rammed earth modular structure.
For the towers' crowning we used another time a subD representation because we planned to produce more detailed stills of those parts, considered more interesting for the comprehension of the original Tatiouine aspect.

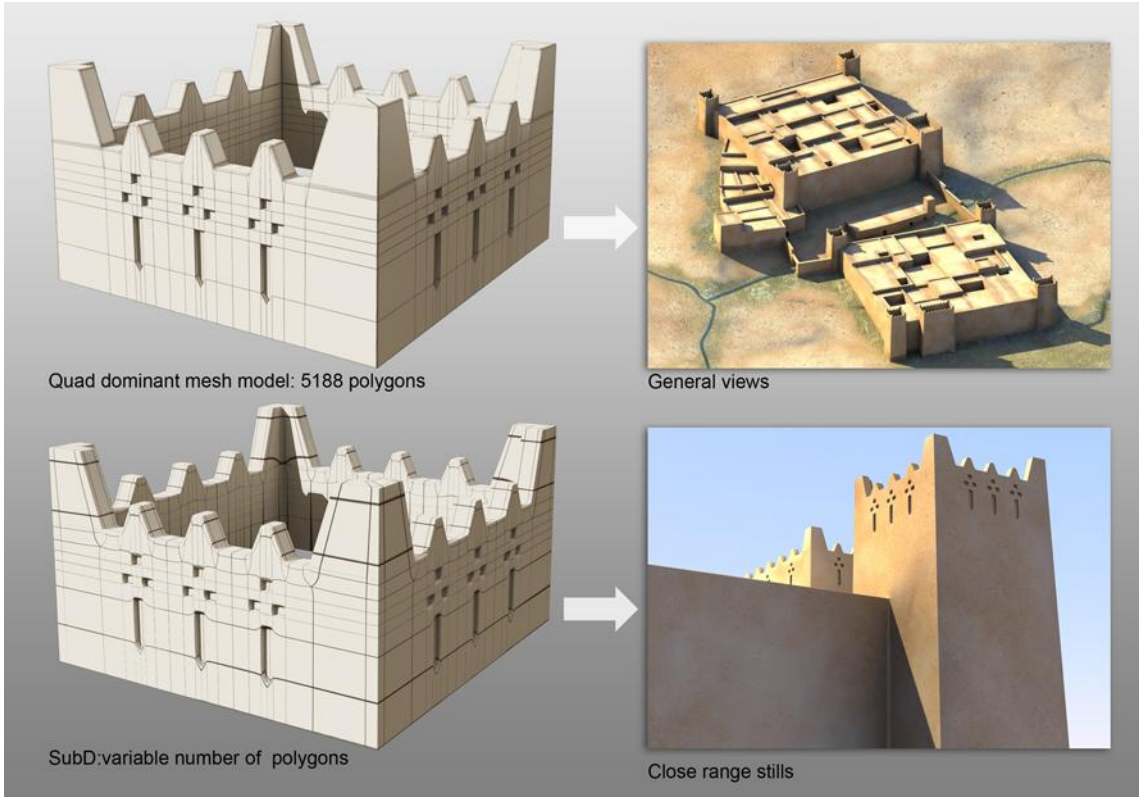

Fig. 10 – Level of detail of the *ksar* model: coarse meshes versus variable level of detail.

Once obtained the digital models of each constructive phase, began the mapping of the 3D geometries on the u,v reference system (GUIDI et al. 2010). Due to the quad-dominant[18] structure of the models (both of simple meshes and subD) the u,v mapping was quite fast and we hadn't to face prolonged sessions of unwrapping tools.
For the texturing we used a combination of techniques: once mapped, a tiled texture was assigned models. The tiled texture was obtained by a high definition photo of a rammed earth wall, and then we used a 3D painter for decreasing the classic repetition effect.
Thanks to the painter it was possible to use other photographic materials for adding realistic details in correspondence of the main edges of the polygonal models.

[18] Quad-dominant means a mesh model created mainly using 4 sides polygons that permit faster selection and mapping in the u,v space.

Fig. 11 – Overview of the *ksar* Tatiouine during the summer of 2010 (Copyright: P. Rodríguez), and overview of the reconstruction of the *ksar* Tatiouine.

Conclusions

The objectives of our research were the obtaining of a digital 3D model capable to describe the current state of conservation of the ksar Tatiouine. Thanks to topographic and photogrammetric survey campaigns it was possible to document with accuracy the current state of this heritage at risk. The use of 3D modeling tools allowed our work team to evaluate different reconstruction hypothesis with special regards to more complex details such the joints between towers and walls and the internal streets patterns. The use of a typological approach for the understanding of the ksar composition, so as a correct geometric survey, gives to the whole reconstruction process a good degree of reliability, but the final product should be considered as one of the possible solutions and not the exact aspect of Tatiouine. The two aspects of the dissemination process are by a side the possibility to let other researchers know the current state of conservation of this heritage, by the other there is the problem related to the anthropic danger due to the lack of maintenance knowledge of the Berber population of Tatiouine.

The other scope of our virtual reconstruction is also aimed at letting the Berbers know the history and the ancient state of their village that once was formed by a solid, safe and confortable complex that should reborn thanks to different kind of aids: not just economic but also cultural, in the sense of coming back to ancient, cheap and sustainable constructive techniques.

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SESSIONS

Lost Cities – Prospections and Hypothetical Urbanistic Reconstructions

The Prediction Model in Archaeology

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Abstract: The Prediction Model in Archaeology is the topic of this paper. Current predictive models are based either on classical methods of applied mathematics (time series analysis, statistics) or on the principles of artificial intelligence (artificial neural networks, genetic algorithms). In many cases, however, there is a lack of predictive models. It is primarily a prediction of spatially coupled problems solved with the aid of GIS. Therefore the special interactive prediction model was designed for usage of ex-post (interpolation) and ex-ante (extrapolation) prediction methods. The multi-criteria approach to the input parameters is applied in the model. There is a multidisciplinary approach in the predictive model, because partial results are reviewed by experts in the field of archaeology, geodesy and computer science. The model is designed for the use in GIS and is based on interactive data entry confrontation with the output spatial objects or phenomena. The goal is an obtaining maximum yield of information from the given input data. The proposed model was tested in the field of archaeology in search of abandoned medieval villages in the surroundings of the Veveří castle.

Keywords: Prediction, GIS, spatial modeling, archaeology.

Introduction

The process of simulation model building generally represents a reconstruction and its way a prediction of the possible existence of phenomena reflecting object investigation. The subject of modeling and simulation is a studying of objects that already exist in reality or they could exist. The paper deals with the existence of objects in a time long past which can be described by the simulation model prediction. The core of the modeling of spatial phenomena prediction model through simulation process is not only a conducting spatial analysis of archaeological data, but also the use of tools for examining the characteristics of landscape elements and factors affecting the occurrence of long-past history.

Results of simulation study will be a complete simulation model for purposes of archaeological prediction. The life cycle of the simulation process is composed of two stages: design and development of simulation model and experimentation with the model. The paper also deals with the various individual stages of the simulation studies in archaeological predictive models. This is through the simulation as a research technique, whose primary objective is the substitution of simulator by certain studying dynamic system. The abstraction of object model solved the archaeological site will be predicted. The objectives are experimented using the simulator for obtaining information on the original scheme. The appearance of the remains of human activity from ancient times can be reconstructed from the results of simulation studies using 3D modeling and visualization.

Modelling and simulation

The subject of modeling and simulation is the study of the objects that may already exist in reality or they could exist. If we deal with the existence of objects in a time long past, it can be described by the simulation predictive model. It is often not possible to describe these objects in examining rationally in all their complexity therefore the description of the investigated object is applied an abstraction (some aspects of objects not important in solving the problem are neglected and insignificant characteristics are described in a way that leads to the manageable solution of the problem). That can't predict the extinct location accurately by describing the object. The modeling system definition is made on studied objects (parameters) and one object can be defined in different systems. It depends on the different frame of reference when the object is observed in various fields of human activity. A different point of view is arising from the existence of parameters that are influenced by various factors depending on the variables. The system called a static system disregards the importance of the passing of time. Experiments in simulation of static system for archaeological predictive model (APM) would represent a simple analysis only connected with the rights geological, climatic and landscape character of the studied area. The system is called a dynamic system if we are considering the passing of time. Time instants of a dynamic system are identified as well as for the abstraction. Experiments in simulation study of dynamic systems offer a wide range of analysis in predicting that can be combined in different options (KRIVY and KINDLER 2001).

It is considered that the system consists of certain elements (entities/elements) in a dynamic system in the modeling process and simulation. We distinguish between permanent and temporal elements. Permanent elements occur in the system throughout its existence. The permanent elements can sort these elements in the archaeological prediction modeling: land use (landscape features – height, slope, exposure to the field), geological and climatic nature of the territory, and others. Temporal elements can entry into the system and leave it again. We consider these temporal elements in APM: a factor of appropriate environmental protection, economic factor, a defensive factor, a cult factor, and other socioeconomic factors.

The dependence of objects in the model of simulation

There are clearly insignificant properties of objects after defining the system to the objects of the investigation. These objects are subjected to closer scrutiny. In our case, the objects of the investigation will be a location of the potential archaeological site in a particular historical period. There are elements that don't enter directly into the purpose of the investigation but it is necessary to take their existence under consideration. Correlation of elements is very important. The interdependence of different variables directs the operation of prediction in historical documents. It can be used an interaction modeling in the simulation process with each comparing factors. These factors are dependent on variables. Interaction of modeling is a strong correlation between the individual elements that can be identified as important factors influencing on the prediction of a particular place. Important factors occurred in the predictive model include the land use factor, the cult factor, economic factors, social factors (socioeconomic factors), a defensive factor and others.

The process of model building

The essence of modeling is a substitute of the investigated system of the model whose aim is an acquirement of information through experiments with model on the original modeling system. Simulation is a research technique. The essence of simulation is a substituting of the considered dynamic system (a system in which we are considering the passing of time) with the simulator. It can obtain information about the original investigation system by experimenting with the simulator. Run of the simulation program can be seen as carrying out a sequence of activities in the order in which they perform their corresponding actions in simulation systems (KRIVY and KINDLER 2001).

Activities (processes) of the model can be divided according to this nature:

- Discrete phenomena – the building of APM is preferable to consider discrete activities that change state only at the time of its completion and their time existence is understood only as a single element set of real numbers. Individual objects can be divided into sections on the coordinates X, Y. It has limits which are spatially defined. There are mostly vector data model.
- Continuous phenomena – they cover the whole territory continuously, the phenomenon can not be stopped (to find the exact limit). We determine the value of the phenomenon in the spot X, Y. It usually is a raster data model.

The values of entity attribute change only at discrete time moments in APM. The reason is clear evaluation of the results in parts of interaction analysis of the process simulation. Clarity is very important in archaeological prediction because only place whose existence has long since disappeared is still considered in this project.

Archaeological predictive modelling

The process of building of the archaeological predictive models is a specific approach and solutions. APM is a tool that should simplify the archaeological research in the field of systems of settlement and land use in the past. APM is a certain degree of accuracy of the probable location of parts of the country which was previously used and which can predict the occurrence of archaeological sites now. The problem of archaeological predicts is solved by experiment sites (areas, packing areas), which typically are not usually distributed randomly, but occur with respect to the geographical environment and settlement organization. The starting point of a correct archaeological predictive model is a finding the interdependence and carefully selected set of factors in the input documents that affect the distribution of archaeological sites. Correct correlation of the setting parameters creates the possibility of identifying sites in the country in which they are to find archaeological sites with high probability (GOLÁŇ 2003; NEÚSTUPNÝ 1994).

Summarize of the input documents and their evaluation in the initial phase of APM is a certain amount of attention and knowledge of archeology (Fig. 1). The expert analysis addresses the first correctness of data entry documents where a database of all documents is created (maps and graphic materials, literary sources, material artifacts). Emphasis will be placed on a database of historical documents that will be used to analyze the influence of time factor. The time factor affects on the every part of the solution prediction model. Any analysis, each base and each output are affected by time factors therefore it is needed the expertise of the historical objects. These objects are changing in appearance and properties from the time. It

is desirable to consult input documents with experts. Interaction of experts is very important to address the process of model building. It represents the experience and expertise in terms of informed people in the fields of archeology who determine the exact rules and parameters for prediction of term solution. The selected documents create a simulation model into base of GIS. The using of all the tools and modules in GIS thematic layers is also important in the process of creation. Model Builder applications, map algebra, 3D Analyst, Spatial Analyst create a full prediction model which can be handled in different ways (MACHÁČEK 2008).

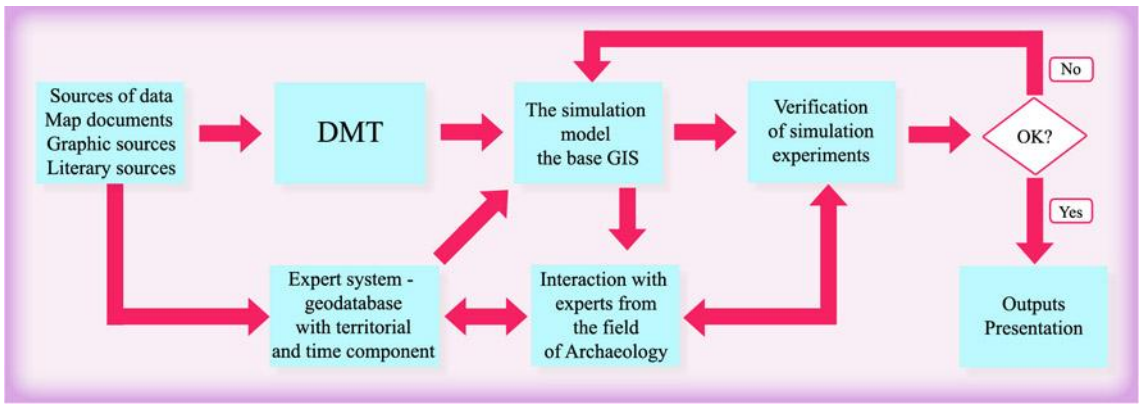

Fig. 5 – Scheme of different parts of archaeological predictive model.

Expert system in predictive models is a using of settings of parameter that will be more precise each thematic layer. Parameters affected the location of the archaeological site are: altitude, slope of terrain, distance from watercourse, communication, religion and others. The outside spatial parameters can be considered a way of behavior of people in the past. Factors that affect the way the behavior of people are as follows: cult factor, economic factor, the factor of environmental suitability, defensive factor, factor of minimum effort and others (Fig. 2).

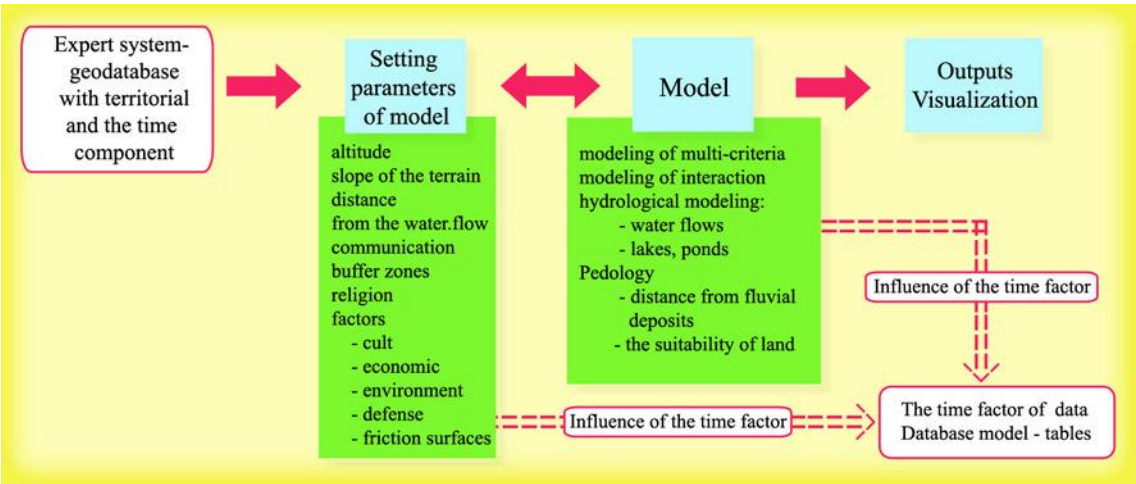

Fig. 2 – Expert system.

The actual implementation of the analysis in the GIS occurs to simulate the presence of archaeological sites after the setting of the parameters of the model arises. Spatial analysis is combined and uses multi-criteria, interaction, hydrological modeling, model of the petrology and others. All created spatial analyzes should be subjected to an influence analysis of the time factor which is used to create a database of historical documents and there is mutual comparison of statistical and graphical output of results in different time periods. The visualization of sites of archaeological locations in relation to their probability is the output of predictive model. The formulation of outputs is specific. It depends on the given site, the terrain and the presentation of appropriate sites for archaeologists (KUNA 1997).

Simulation study

The core of the whole project is the creation of simulation studies which will result in a complete simulation model. The whole process of simulation is implemented in ArcGIS software. Basic diagram of connection is in the picture (Fig. 3) where each of the steps in the modeling is presented. In the first stage of the creating is a preprocessing which is usually the largest component of the process. It builds an important part of the simulation and its associated archaeological prediction continuously. The different types of models are used in this stage. The modeling of multi-criteria, interaction modeling, hydrologic models, erosion models and others apply for purposes of archaeological prediction. Reciprocal correlation model eliminates the uncertainty of the location of potential archaeological sites. The final part is the post-processing which connects the individual outputs of each simulation model.

The life cycle of the simulation process (studies) consists of 2 stages: design and simulation model development and experimentation with the model. The procedure of making is described at each step of its implementation (KAVIČKA 2005).

Phase 1 – Design and development of simulation model

Indication of the object examination and issue of stylization

Creation of archaeological predictive model using the simulation method is a process where objects are destroyed by examining medieval settlements and their prediction. Defined object of investigation is experimented on the research methods of simulation. Prediction of the location of the settlement will be at the core of the project simulation model. The suitability of the site would result from different combinations of spatial analysis, which will describe the sub-objects examination.

The setting aim of project and time schedule

The aim of project is a using of prediction of defunct areas and their interactive modeling by spatial analysis in ArcGIS software. Time schedule of the project requires extensive time reserve for the procurement of necessary documentation, documentation and input data for progressive graphics verification. Part of the definition of reserves is the control of technical and substantive correctness of input data to avoid mistaken and negative influences. The solution for spatial analysis requires a large proportion of the total schedule of the simulation model.

Determination of the system

The abstraction is applied on the object of examination. It specifies the simulated system (the original). It is needed to determine the correctness of input data and their thematic distribution accurately. Suitability of the material is an achieving the objectives and solves problems without the need for further analysis and experiments.

Collection and analysis of data correctness

Data collection and their analysis take place parallel with the formation of the conceptual model. The process of the data collection is the most important part of the project. Phase of search suitable materials requires considerable attention because of a streamlining of downstream spatial analysis. The input data are important for decision-making rules relating to the issue of conflict resolution. The searching for documents in them includes communication with the various institutions which represent the risk of negative feedback. Therefore it is important to ensure the correctness of received documents to prevent false information at a lower number of input data. The process of data collection and analysis is dependent on the requirements which have been set in the conceptual model solutions. The concept of the model will set the direction of its own collection of input documents.

Development of simulation model

The appropriate data structures will be designed and implemented in ArcGIS software. It is necessary to determine the main parameters of which it will be based, and which will form the skeleton of model. The entering the following parameters will be important for directing operation of the simulation model. Appropriate tools can be the 3D Analyst, Spatial Analyst, Map Algebra which offer other components of ArcGIS software. An interaction between these instruments is very important.

Verification of simulation model

Verification of functional correctness of the simulation model represents the first phase of the control of component interdependencies that were initially established in the conceptual model. There are different methods for testing the functionality of input and interaction of sub-documents for verification of archaeological predictive model. It will be applied the main methods of analysis using spatial interaction modeling, assessment of multi-criteria, land use analysis and others. Testing of the processes of interaction requires a great deal of knowledge (study of the historical sources, archaeological documentation, documents representing landscape features, geological and climatic characteristics and other countries). Deficiencies found during verification lead to legal intervention in the process of design and production simulation model.

Validation of simulation model

Validation is a testing of the veracity of behavioral simulation model and the correctness of the result of processes of spatial analysis. Implementation of validation in itself includes a variety of these methods (KRIVÝ and KINDLER 2001):

- Method of compare with reality – using comparative methods of the dealing with concept of using statistical methods. It is a using processed archaeological data of existing archaeological sites, the State Archaeological Database System, exploring the surface collections solutions to existing sites.

- Compare with other models – validation that will be created to compare each model with fundamentally a different structure model. Examples include models using modeling of multi-criteria based on fuzzy logic, neural networks, interactive modeling using hydrological analysis, etc.
- Empirical method – using expert assessment by an independent expert. Consultation various parts of the concept and created simulation model with knowledgeable experts in the field of archeology.

Negative results of the validation may lead to structural changes in the conceptual phase of the simulation model. Then it is necessary to review the correctness of input parameters.

Phase 2 – Experimenting with the simulation model

The simulation test plan

The plan attempt depends on the frequency and accuracy of input documents. The proposed plan may be modified based on progressively the obtained results. It is necessary to consider the impact of the time factor of historical documents and their relation to the contemporary world.

Implementation of the plan and process analysis

GIS software includes itself in the mathematical combination of spatial data to create derived data which may provide new insights into natural and anthropomorphic phenomena. These data can be further used in the geological models for predicting the suitability of reverse land for agriculture or predicting erosion potential or the potential deployment models in archaeological sites. The simulation model would allow a defining, analyzing and evaluating residential development followed in the past, the selected area on the basis of criteria determined from revised and localized archaeological data. Mathematics-simulation model for predicting in archeology works based on the known archaeological patterns and calculations are carried out by the facts. The description and analysis of the human behavior (a simulating the actual behavior) is the core of the process simulation model. We try to model the social dynamics of the population between the individual analyzes and predict the possible occurrence of a real historical settlement.

The model uses a deliberately thought processes from individual to the general, the models, patterns, concepts of factors that do not only features of the landscape, but also focuses on the patterns and effects resulting from the spatial position. Created model simulates the dynamics of changes in functional use of space in this area by combining the results of the analysis. The efforts to understand and correct evaluation of often very complex behavior of a spatial system are usually difficult because of the resulting documents, which represent an informed decision and simulation caused by the influence of individual factors in the area.

It can be used the wide range of alternative applications as Model Builder for modeling purposes as a representation of the real (historical) world. The ArcGIS software can create models of “localization” process model (variables, parameters and their influence tackle) and model description (description of examined issues). The benefits of the Model Builder application are a creating its own sequence of functions and their parameterization (modification of function parameters, respectively instruments), modification of storage functions, scripting languages and others. The iteration of the individual process creates detailed and final output in spatial analysis in the application.

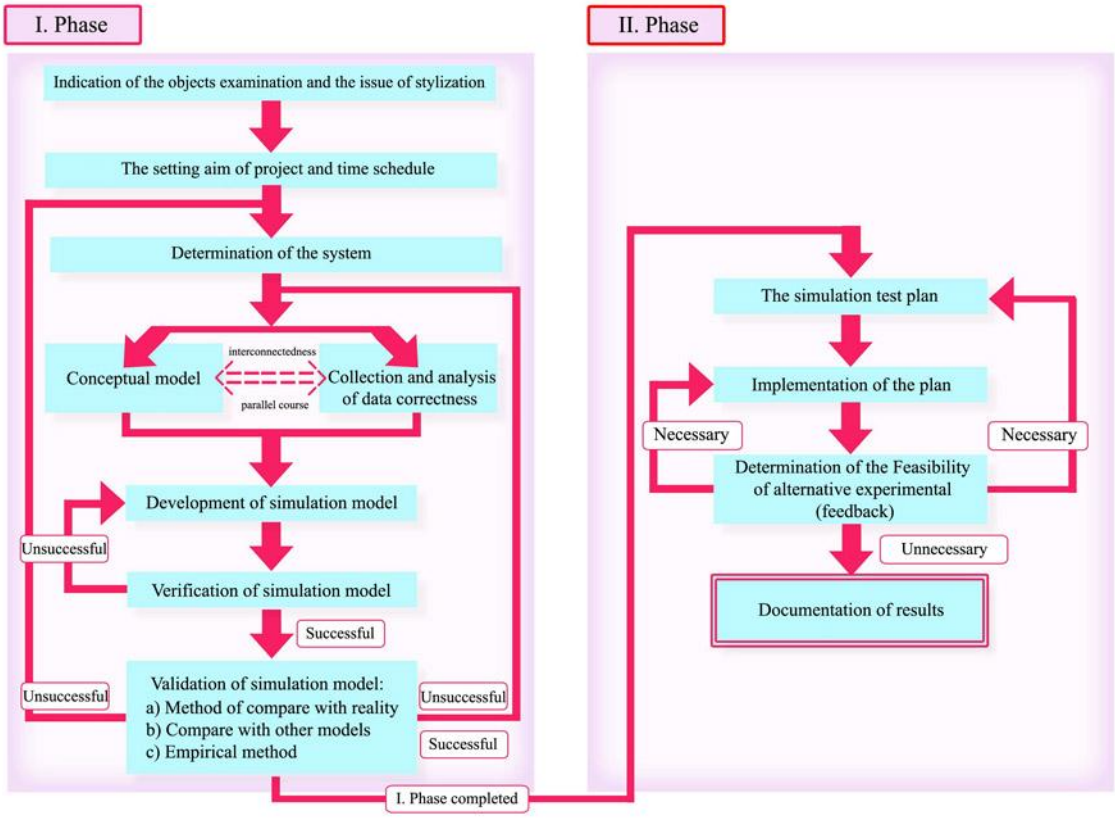

Fig. 3 – The life cycle of the simulation process.

Determination of the feasibility of alternative experiments (feedback)

It is not enough just to work with absolute variables that reflect the modeled variable without reference to other modeled quantity, time period and area when evaluating the specific factors of historical events. It is necessary to have the values of these variables in other situations and compare their relative manner proportional method. Comparison can be done by absolute difference, comparative index (time index, geographic index, and mixed material index). Confrontation of the output analyzes with archaeological documents and papers states the possibility for the alternative experiments because of the low reliability of the results for the final prediction of perished areas. The process of deciding on the appropriateness of the models and their combination for predicting the archaeological site requires a great deal of knowledge about the issue as well as discussions with skilled and knowledgeable professionals. Although the location of archaeological state prediction may not always be complete, ambiguity and uncertainty of determining the place can be alternate with other spatial analysis of multi-criteria modeling. Therefore it is important to confront your knowledge of simulation modeling with experts to determine the alternative solutions.

Documentation of results

Graphic outputs of simulation model results are heterogeneous. The mapping outputs are useful for the purposes of archaeological prediction models and have related factors which affect the decision-making on the suitability of sites of potential archaeological sites. The combining of the resulted layers of analysis and graphical presentation is an excellent instrument for intuitive visualization of the possibility of settlement. The archeological site can be reconstructed through simulation in the form of 3D models directly applied to the

solved area. For example: a making of a real contemporary look of the village by using simulations according to the available historical documents helps archaeologists in the visual orientation of the territory. 3D model of the ancient settlements is a part of a comprehensive analysis of the simulation study. Its combination with the spatial analysis moves simulation process to concrete results with decreasing percentage of localization uncertainty of potential archaeological sites.

Conclusion

The paper deals with the existence of objects in a time long past, which can be described by the simulation model prediction. The core of modeling of spatial phenomena of prediction model through simulation process is not only a conducting spatial analysis of archaeological data, but also the use of instruments examining of the characteristics of landscape elements and factors which affect the incidence of long-past history. The simulation model is linked to ArcGIS software environment that offers a method of simulation by spatial modeling. There are considered factors in the spatial analysis that affect the suitability of the location of potential archaeological sites. The experiment phase in the simulation study, which consists of two phases, is in various combinations of post processing analysis of the results.

The simulation of the archaeological prediction provides us the abstraction of object model solved for the archaeological site. Simulation in the GIS environment is a suitable tool for visual representation of dependencies of the variables and factors of modeled site. The archeological site can be reconstructed through the simulation in the form of 3D models and visualization applied directly to the solved area. Combining of 3D models with spatial analysis reduces the percentage of localization uncertainty of potential archaeological site, for better visual connection of the location with reality and its possibilities for the existence of historical settlements.

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The civilian town of Carnuntum (Lower Austria) in time and space

A multi-layered approach towards the reconstruction of urban transformation

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Liv|in' past (part of Kunst & Kultur – Verein zur Förderung kultureller Aktivitäten)

Outline: Based on the results of various extensive excavation-projects in the Roman civilian town of Carnuntum (Lower Austria) this paper wants to combine the data of geophysical and aerial prospection with the multi-layered, four-dimensional structure of the archaeological record. Transcending the conventional, rather static interpretation of prospection-data, this approach will provide a valid historical synopsis of the dynamics and continuities of urban development in Carnuntum from the late 1st to the early 5th century AD.

Abstract: Following the first major excavations by Erich Swoboda in the 1940ies and 1950ies, the urban structure of the Roman provincial capital of Carnuntum (Lower Austria) has frequently been the subject of scientific research. Recently, a new 3D-model was elaborated, showing the urban and suburban landscape of Carnuntum in its largest extent during the 3rd century AD. Abundant geo-physical and aerial prospection data formed one of the main sources for this model. Despite the amazing scrutiny and thoroughness in assessing such kind of archaeological information there is still a major deficit in extrapolating aspects of transformation and chronological change from the rich data-sets. Thus, the proposed paper wants to clarify the confidence limits of both prospection and excavation in an urban environment, putting both into a reasonable interpretive balance. As a case study we will use the vast excavation projects conducted in the civilian town of Carnuntum from 2001–2011 which yielded a huge amount of valuable information about the initial design and the diachronic evolution of the Roman settlement. By evaluating the archaeological record it will be possible to reconstruct the basic parameters of town planning like street grids and building lots. In comparison to the available prospection data (e.g. covering the areas of the Forum as well as most of the eastern part of the town) the wider scope of urbanistic change and continuity can be tackled, leading to a synoptic picture of a settlement in time and space which transcends the rather static qualities of a single model.

Keywords: Carnuntum, prospection, evaluation

The archaeological landscape of Roman Carnuntum, located 50 kilometres to the East of Vienna, has been thoroughly investigated for over 120 years. At the beginning of the 20th century, huge excavations uncovered the legionary fortress and the surrounding settlement. During the 1950ies, also in the so-called Zivilstadt, a non-military town provided with the official status of a *municipium* under the reign of Hadrian, a complete quarter of houses, streets and building-blocks was excavated. Of course, all those activities yielded a vast amount of archaeological and architectural data. However, many crucial aspects of Carnuntum's urban history still remain unknown. For example, until the 1980ies it was quite disputed whether the Zivilstadt had actually been protected by city-walls; only random data could be gathered concerning urban

infrastructure like water-supply and street-system; and, last but not least, apart from the amphitheatre and the well-known *Heidentor*, many of the most important public buildings were still unknown (Cf. STIGLITZ 1977; JOBST 1983: 124–128, 130–136; SCHEDIVY 1986: 111–118; CENCIC 2004: 16–20; KANDLER et al. 2004: 35–41; GUGL 2005: 108 f.; HUMER 2006; KANDLER 2008). In this regard, the archaeological prospection of the last ten years helped a lot in clarifying the blurred picture. To be sure, there has been intense work on aerial photographs long before this period. However, it was the impact of geomagnetism and georadar which finally led to a groundbreaking leap forward in understanding the urban structure of Roman Carnuntum (Fig. 1). Maybe the most prominent example was the detection of the monumental city-centre, the Forum, from 2001 onwards (NEUBAUER et al. 2001: 39–48 figs. 9–10; KANDLER et al. 2004: 37 fig. 17; 43 f. fig. 26; EDER-HINTERLEITNER et al. 2006: 282 f.; KANDLER 2008: 104 fig. 8).

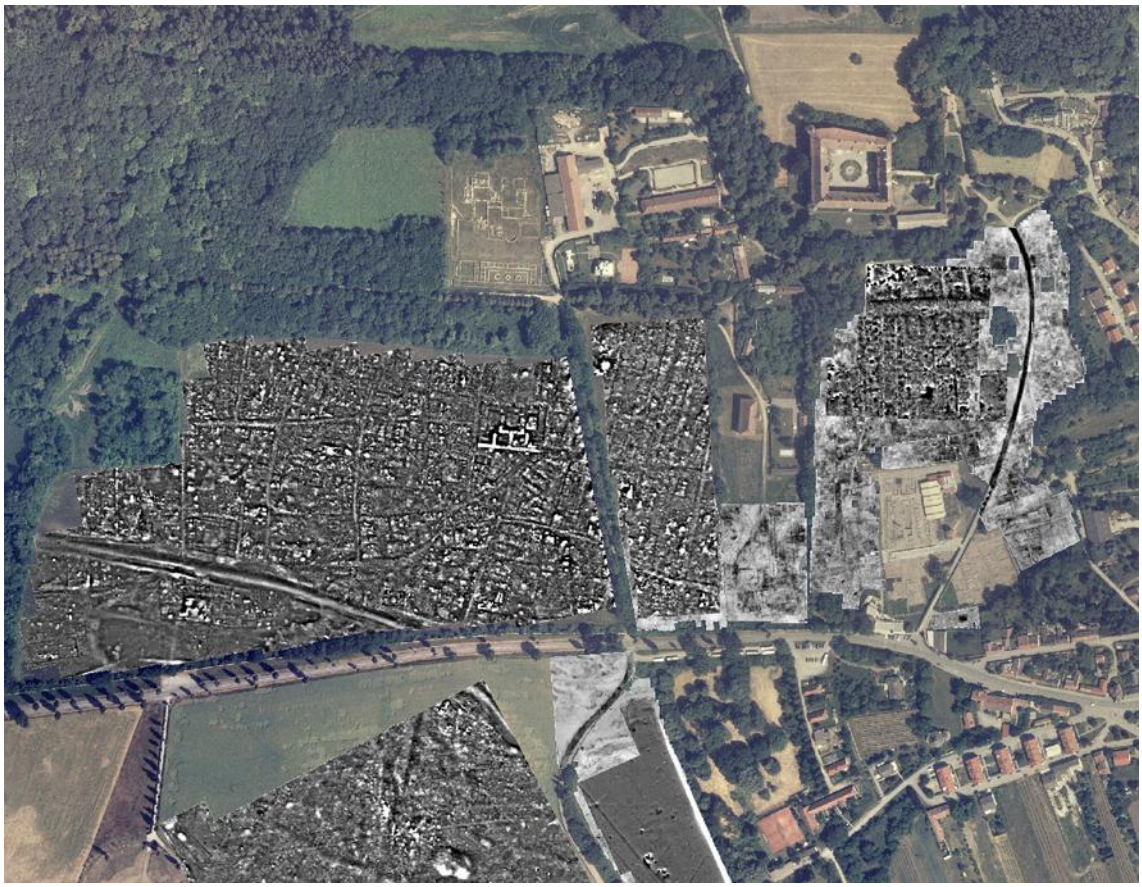

Fig. 1 – Aerial and geophysical prospection of Carnuntum (Archäologischer Park Carnuntum; prospection data provided by ArcheoProspections [2001–2010]).

Despite such good news, if the small size of actually excavated area is compared with the huge amount of prospected but not excavated land it seems to be very appropriate for this paper to be included in the session on „Prospection and hypothetical urban reconstruction“. However, the main goal of the following pages shall be to demonstrate the way in which we can try to minimize speculation in our hypotheses by a combination of different methods. In a complementary analysis, also the inherent risks in the use of just *one* archaeological or prospective method will hopefully become clearer.

In his highly influential book „The Image of the City“, published in 1960, Kevin Lynch was able to clarify by how many different factors our perception of urban views and urban structure can actually be influenced (LYNCH 1960). He also showed quite clearly, that urban identity itself is always basically defined by the organisation of space, the shape of buildings and human movement through architectural landscapes. To put it in a nutshell: Every kind of *urban* perception as a matter of fact must be *human* perception. But this human perception is not just based on spatial structure, but also on chronological transformation. It already starts with the climate and the different hours of the day: In every city there are quite heterogeneous atmospheres and impressions, depending on time and weather. By daylight, cities look quite different than during the night (Fig. 2). Darkness not just influences human orientation in the framework of the city but also gives a different impression of building materials and surfaces than the bright light of day. All those factors strongly depend on human, subjective perception, as well as on their interpretation regarding certain rules and tastes, learned in a process of social interaction. According to this observation, perception of a city must always be treated as a deeply human and social phenomenon. Despite of this focus on individuals, also from an archaeological and architectural point of view we can gain a lot of information which helps us in reconstructing the complexity of such urban images.

Fig. 2 – Left: Boulevard Montmartre (1897), Camille Pissaro (http://en.wikipedia.org/wiki/File:Camille_Pissarro_007.jpg). Right: Boulevard Montmartre (1897), Camille Pissaro (http://www.repfineart.com/images/Camille-Pissarro-The-boulevard-Montmartre-at-night.jpg).

Kevin Lynch’s approach has been further adapted by the German sociologist Martina Löw (BERKING and LÖW 2008; LÖW 2008: 65–139). In her model she proposes an even more active role of society in shaping, conserving or transforming urban space. This concept of „urban Eigenlogik“ was thoroughly investigated by her research cluster over the last six years. The word „Eigenlogik“ is conceived as a combination of structures and processes, strengthening or weakening their respective meaning for urban communities and built environments by constant dialectic communication. The result of several socio-architectural studies connected to the concept of „Eigenlogik” was of little surprise to most sociologists, although for archaeological studies it has important implications: Every single city follows its specific rules and patterns. Of course, there are certain possibilites to establish common structures and urban typologies. However, they are not *as* important for daily urban life and its transformation over time and space as architects may always

have desired and theoretical urban planners may often have imagined. Concerning the archaeologist’s point of view, which deals with the historical importance of buildings and spaces for the concept of urban „Eigenlogik“, the studies of Löw and her team have not come to a satisfying end.
Departing on the one hand from Lynch’s „Image of the City“, on the other hand from Löw’s concept of „städtische Eigenlogik“, our archaeological mind naturally switches to reconstruction, visualisation and 3-dimensional modelling. Indeed, over the last two years an impressive 3D-Model has been built, showing the whole archaeological landscape of Roman Carnuntum on a large scale (GUGL et al. 2011) (Fig. 3). The civilian town itself is distinguished by a clear urban structure with a wall-circuit, streets of different sizes and directions, building-blocks and monumental public buildings like the Forum and a central public bath. And, indeed, this is a most beautiful „Image of the City“.

Fig. 3 – The 3D-modell of Carnuntum as presented in the Archaeological Park (Archäologischer Park Carnuntum; photo: D. Maschek [2011]).

However, what does it tell us about historical aspects of urban transformation? The question is quite simple: Nothing. The model is showing an idealized city as it could have existed around 200 AD. That was the time when Carnuntum was elevated to the rank of a *colonia* by the emperor Septimius Severus. This specific historical event is often hypothetically connected to the maximum prosperity of the Roman town; it was basically this assumption which led to the chronological choice for the model. However, some concessions to the public had to be made: For example, the model also includes the so called *Heidentor*, probably the best-known Roman monument on Austrian soil. This four-sided triumphal arch was erected in the 4th century AD – so it is a real odd-man-out in a model of the early 3rd century[19]. There are several other details pointing to a certain inconsistency, but those shall not be at stake in the present paper. Quite on the contrary, we want to show the high potential of a multidimensional analysis including the complex aspects of time and space by combining prospection and archaeological excavation, which finally provides us with the means for reconstructing urban change on different levels.
Following the excavation of two coherent building blocks in the so-called „Spaziergarten“ of Schloss Petronell (Fig. 4) by Erich Swoboda in the 1940ies and 1950ies, the structure of the Roman civilian town became to some degree a point of interest for further research.

[19] The authors stated their intentions as follows: „Im Modell wird die topografische Lage des Monuments zwar angegeben, das Heidentor als Bauwerk aus der zweiten Hälfte des 4. Jahrhunderts dient aber nur als Orientierungspunkt und wird nicht wie die anderen antiken Gebäude als bereits bestehendes Objekt im Modell nachgebildet“ (GUGL et al. 2011). However, this level of sophistication is not very likely to be reached by the common visitor, especially due to the complete lack of additional scientific description on site.

Fig. 4 – Excavation areas in the so called "Spaziergarten" in Carnuntum (Layout by Liv|in' Past 2011, Aerial photo provided by Archäologischer Park Carnuntum).

Recent archaeological investigations, which have been conducted on the southern building-terrace with Houses I-V and in the area of the so-called Insula VI since 2001, yielded a huge amount of new data contrasting with some of the more traditional interpretations (JOBST et al. 1988; HUMER and JOBST 1990; HUMER et al. 1991; HUMER and RAUCHENWALD 1995; HUMER 2002; KANDLER et al. 2004: 41–43; RADBAUER and HUMER 2004; HUMER 2006: 272 f.; HUMER et al. 2005; BAIER et al. 2007). The first important approach towards a holistic analysis of the early Roman settlement patterns has already been made by Christoph Baier for Houses I and II as well as for the north-eastern area of Insula VI (BAIER 2008). However, this extremely well investigated part of the civilian town can also be put into the context of recent archaeological and geophysical data from the so-called Spaziergarten and Tiergarten further to the North and to the West. From the late 19th century onwards, several excavations have taken place in those parts of the town, lasting well into the beginning of the 21st century. Thus, the archaeological record seems to be more than sufficient to allow some basic conclusions about urban development in the 1st and 2nd century AD, and also to provide the basis for an analysis of continuity, change and the „Image of the City" (Cf. MASCHEK 2011).

The area which was excavated in the 1950ies in the so-called Spaziergarten of Schloss Petronell shows some very distinctive divisions even at first glance. There are several partitions, defined by the lines of four streets with a rough orientation from East to West and from North to South, respectively (Cf. KANDLER et al. 2004: 36–38 figs. 16–18; HUMER 2006: 271 fig. 1; EDER-HINTERLEITNER et al. 2006: 286 fig. 8; KANDLER 2008: 105 fig. 9) (Fig. 5). The so-called Northern Street can be identified with one of the larger

East-West corridors leading through the fabric of the town. Basically parallel to this axis and also paved with stone-slabs runs the so-called Southern Street. These two streets, oriented from East to West, were connected by two other paved pathways, the so-called Western and Eastern Street.

Fig. 5 – Left: Aerial view of the “Spaziergarten” (D. Maschek). Right: Map of the “Spaziergarten” (D. Maschek).

Even from this very basic layout we can draw some important conclusions about the urban system (Fig. 6 left): The four streets themselves are defining a building block with a not quite rectangular ground plan which has been confusingly named „Insula VI“ (HUMER 2006: 273) (Fig. 6 right). In comparison to the southern part of the town-quarter, this Insula VI is situated on a significantly lower level due to the original topography with sloping terraces. At first glance it is not possible to recognise the same regularly planned layout in the dwellings of the southern terrace.

However, during the recent investigations it was also possible to gain vital evidence for historical processes which shaped the image of the place in a much more complex way than usually has been assumed. This can be illustrated by the excavations in the area of Insula VI (JOBST et al. 1988: 194–201; HUMER and JOBST 1990: 28; HUMER et al. 1991: 121–126; HUMER and RAUCHENWALD 1995: 284–286, 288–293; CENCIC 2004: 104 f. tab. 13; MASCHEK and HUMER 2006; 2007; MASCHEK 2010b: 266 f.; Cf. MASCHEK 2010a: 29; HUMER and KONECNY 2007a; 2007b; 2007c; 2008: 572 f.; MASCHEK and HUMER 2008: 569). From the beginning of the settlement in the late 1st century AD the Insula as a building block was strictly divided into five long parcels, oriented from North to South, measuring between 13,50 metres and 14 metres. In the first building phase dating to the last quarter of the 1st century AD, the two easternmost parcels of the block were separated by wooden fences. Between those fences a pathway, partially paved with gravel, was located. In the North and South of this area we can trace the extraction of clay in huge pits. Facilities for the refining of the clay and some wooden buildings were located on a plateau in the centre of the westernmost parcel. During the second building phase in the reign of Hadrian it is still possible to discern distinctive functional patterns, the Northern part being obviously used in another way than the rest of the parcels. In the

area of the plateau as well as in the Eastern part two stone-buildings with identical layout were erected. Both of them had huge courtyards to the South, also containing smaller buildings, probably for living purposes. Further to the North a huge structure with a foundation of stone pillars was built. Its East-Western orientation and the architectural fabric were distinctly differing from the southern buildings, also indicating a difference in urban planning (Cf. MASCHEK 2011: 34–36).

Thus, it is possible to postulate two different stages in the layout of Insula VI. After a first stage, in which the outlines of the building block itself were defined, a second stage of surveying led to the internal separation into five stripe-shaped building-lots (so called *strigae*); the Northern area of the Insula accordingly was shaped like a stripe, but its orientation was from East to West. From Hadrianic times onwards this northern parcel was equipped with a portico running along the so-called northern street. The parcels themselves were approximately 52-53 metres long. The ratio of length to width therefore was 4:1. The same ratio was used for Houses I-V on the southern terrace. Breaking it down to the Roman foot, the *pes monetalis*, the parcels were 45 feet wide against a length of 179 feet.

Fig. 6 – Left: Street network and parcels (D. Maschek; prospection data provided by Archäologischer Park Carnuntum and ArcheoProspections [2006]). Right: Map of Insula IV (D. Maschek).

In the building block of Insula VI, five stripes oriented from North to South were combined with one stripe with identical dimensions oriented from East to West (Fig. 6 left). This area was surrounded by the four streets, which, according to the Roman surveying system, can be named as *cardines* and *decumani* due to their orientation. Thus, the building block had an ideal layout of 66,625 on 66,326 metres or 225 on 224 Roman feet. Its irregular shape obviously was a direct result of the sloping topography. Much more regularly shaped building blocks are visible in the prospected area to the North of Insula VI (Fig. 6 right). In this part of the town the ideal layout of 225 on 224 feet was obviously implemented. On the other hand, in the building blocks of the southern terrace three parcels each were clustered in a single row, only separated by narrow

pathways. Those groups of three parcels were 179 feet long and 135 feet wide (Cf. MASCHEK 2011: 35, 43 fig. 2).

Talking about urban planning, the eastern part of the civilian town of Carnuntum in the late 1st century AD was structured by a grid of rectangular blocks, enclosed by *decumani* and *cardines*. Every one of these building blocks had an internal division into five parcels. However, there is strong evidence pointing against the idea of a *totally* planned urban fabric. For example, a part of the town to the South of the Forum already excavated in 1892 shows an oblique system of streets and small parcels of quite irregular shape (STIGLITZ 1977: 618 f.; JOBST 1983: 153–156; KANDLER 1985: 144 fig. 1; KANDLER et al. 2004: 47 f. fig. 30). Furthermore, the prospection data of the hitherto unexcavated Forum provide us with a street partially cut by the Forum-complex on the South-East.

This street is oriented in an oblique way and connects to the *cardo maximus* at the eastern flank of the Forum which is almost parallel to the *cardines* in the eastern half of the town. The Forum itself is 64,5 metres wide and 142 metres long. Thus, it is obvious that the monumental complex does not just have the same orientation, but also the basic dimensions of the urban system which was implemented in the eastern part of the town in the late 1st century AD. Furthermore, the Forum had exactly the size of a double Insula; it was shaped as a huge rectangular block, limited by the *decumanus maximus* to the North and the *cardo maximus* to the East (NEUBAUER et al. 2001: 45 fig. 10; KANDLER et al. 2004: 37 fig. 17; 43 f. fig. 26; EDER-HINTERLEITNER et al. 2006: 281–285 figs. 1–4; KANDLER 2008, 104 fig. 8). We must admit that up to now it is not possible to date the establishment of the Forum with any precision due to the nature of prospection data. Nonetheless, its structural correspondence with the eastern part of the town leads to the assumption that one of the cores of the original, pre-urban *vicus* should be located to the South-West of the Forum. The street pattern further to the West seems to contain rectangular Insulae which were oriented from East to West, contrasting with the blocks in the eastern half of the town. It is possible that these two systems of building blocks should be also taken as indicators for two different chronological stages of urban growth, though it would require further excavations to clarify this hypothesis.

Apart from the basic structure and division of urban areas, the second major component in defining the „Image of the City“ and its transformation is formed by the use and furnishing of built space. Regarding this aspect, only the visualisation of archaeological remains gives us a satisfying though hypothetical impression. For the use of space in the civilian town of Carnuntum from the late 1st century to the first half of the 2nd century AD the archaeological record documented by thorough excavation provides us with evidence which could not have been gathered by prospection alone. In late Flavian/early Trajanic times the limitations of the several parcels on Insula VI can be detected for the first time (Fig. 7–8); they consisted of fences, log-trenches and pathways paved with gravel. Also on the southern terrace the internal structure of the building block had already been physically defined. In the areas of later Houses I and IVb-c good evidence for wooden architecture could be gathered; those dwellings seem to have served for both residential and productive purposes. On the parcels of later Houses II, III and V huge quantities of raw building material like gravel and clay were extracted. The same pattern of exploitation can be traced in the eastern part of Insula VI. However, the findings from this area seem to indicate the presence of military personell, and the huge refining and storage facilities could support an interpretation of this place as a central point of collection and re-distribution. The two parcels of the later bath-complex and the central parcel of Insula VI had no specific

use at all. The natural sloping terraces of the area were diligently used in favour of the respective building-projects; there is no sign of major artificial intrusions or topographical changes.
The material fabric of the buildings was dominated by wood and clay; at least for the more important dwellings the use of roof-tiles and wall-plaster can be inferred from the archaeological record (MASCHEK 2011: 37. Cf. BAIER and HUMER 2007: 691 f.; BAIER et al. 2007: 188–194, 224 f.; MASCHEK and HUMER 2007: 687; BAIER and HUMER 2008: 566 f.; BAIER 2008: 28–30; HUMER and KONECNY 2009; MASCHEK 2010b: 266).

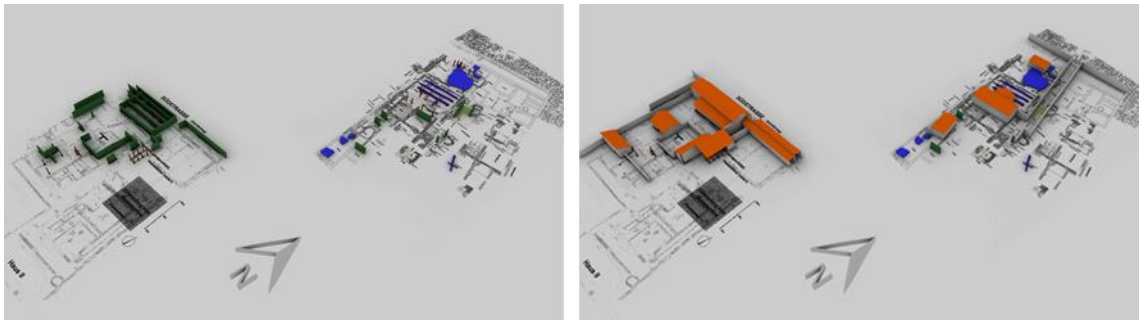

Fig. 7 – Left: Stage 1, 90–120 AD, modelling walls and pits (Liv|in' Past 2011). Right: Stage 1, 90–120 AD, modelling roofs (Liv|in' Past 2011).

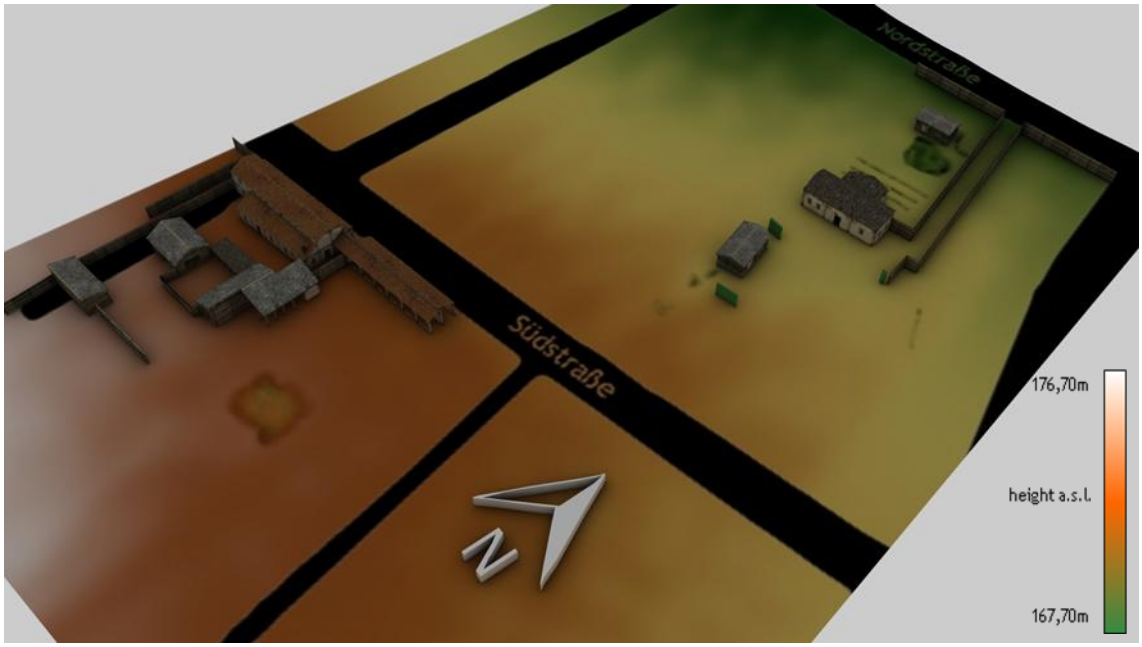

Fig. 8 – Textured model of this building period; based on terrain model with height references (Liv|in' Past 2011).

This kind of spatial management lasted until approximately 120 AD. At this time, the architecture of Insula VI was radically reformed (Fig. 9–10); on the other hand, the functional context on the southern terrace did not change apart from the adaption of mudbrick-walls. The easternmost part of Insula VI was from now onwards occupied by two massive stone-buildings which did not yield any evidence for residential use. Instead, the buildings probably functioned as facilities for the storage and further processing of wheat. The area of the later bath-complex still was a piece of wasteland. After all, we can quite confidently state that Insula VI was

used as a residential quarter neither in the first nor the second building phase. Quite on the contrary, the area of Houses I, II and III at the same time obviously served both for living and production. The three parcels seem to have been connected. Thus, it is more than probable that the owner of the solid building on the westernmost parcel was also owning and using the two building further to the East. Streets paved with gravel and a mixture of plastered stone-walls, tiled roofs, wooden cabins and stripes of open wasteland were the significant ingredients of early 2nd century’s urban fabric. Also the original topography was transformed by building activities. In comparison to the first stage of development even such seemingly stable factors like landscape and environment had already changed a lot (Cf. MASCHEK 2011: 37; MASCHEK and HUMER 2006: 690 f.; BAIER 2008: 31 f.; MASCHEK 2010b: 266 n. 8).

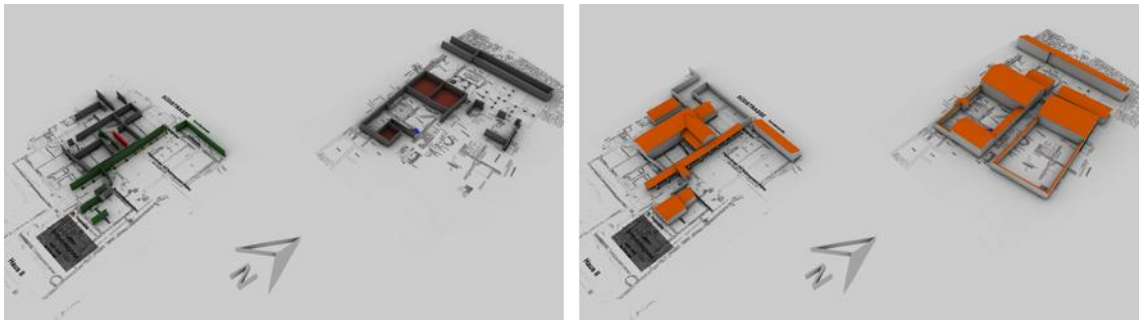

Fig. 9 – Left: Stage 2, 120–140 AD, modelling walls and pits (Liv|in’ Past 2011). Right: Stage 2, 120–140 AD, modelling roofs (Liv|in’ Past 2011).

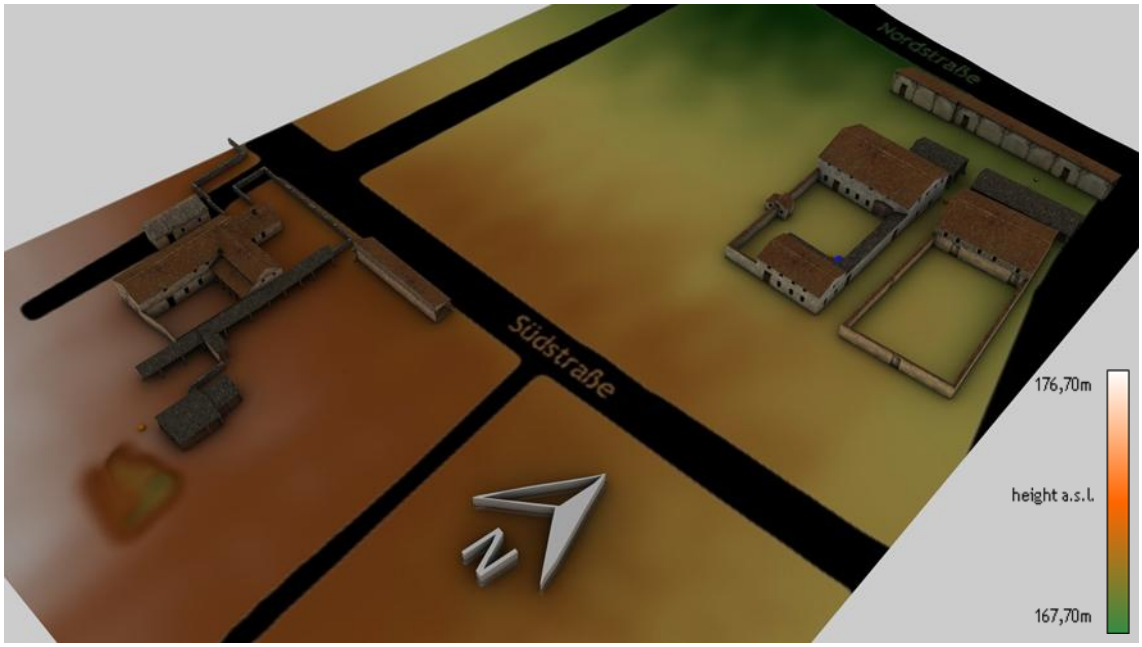

Fig. 10 – Textured model of this building period; based on terrain model with height references (Liv|in’ Past 2011).

The third stage of urban development can be dated to the late years of Hadrian when the bath-complex in the western third of Insula VI was erected. From the excavation results it becomes quite clear that the parcels of the southern terrace still had not fundamentally changed their respective functions. Later House I on the south western edge was re-built with solid stonewalls. The two parcels further to the East contained

facilities for drying straw and wheat and a huge structure interpreted as a stable for cattle. Obviously, this combination of buildings indicates the use as a considerable farmstead with a representative manor. Such kind of urban farms and their livestock must have made an important impact on the overall perception of the town's fabric at this time. Even major changes took place in the area of Insula VI. Apart from the huge bath-building the central parcel and the northern part of the western building lots were fundamentally re-designed: through the addition of dwellings with a high capacity of rooms for accommodation and food processing, the density and functionality of the respective architecture could be radically improved. The buildings in the eastern part of the Insula which already had been raised twenty years earlier still remained in use. Some new rooms and structural adaptions did not change the overall concept. Thus, in some parts of the town-quarter we obviously are dealing with a significant and visible densification of the urban fabric. Other parts had a surprisingly un-architectural, non-urban aspect with little traces of solid buildings, partially melting into the surrounding countryside at the edges of the town. Such areas must have been perceived as a clear counter-image to public monumental architecture and to the closed facades of representative building blocks (Cf. MASCHEK 2011: 37 f.).

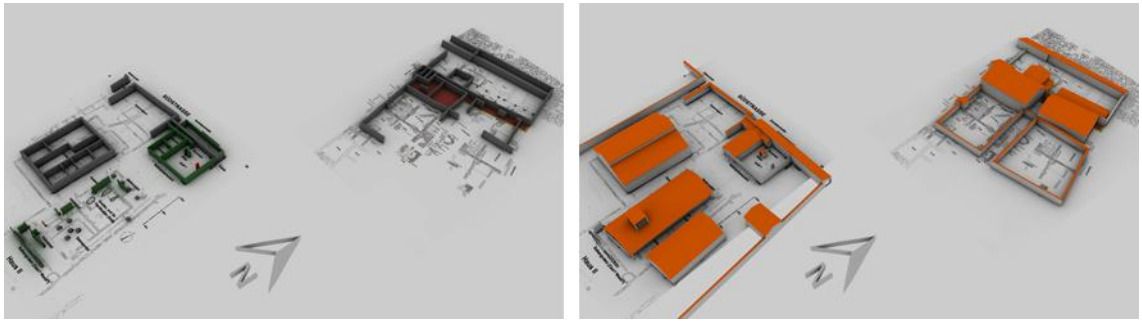

Fig. 11 – Left: Stage 3, 140–200 AD, modelling walls and pits (Liv|in' Past 2011). Right: Stage 3, 140–200 AD, modelling roofs (Liv|in' Past 2011).

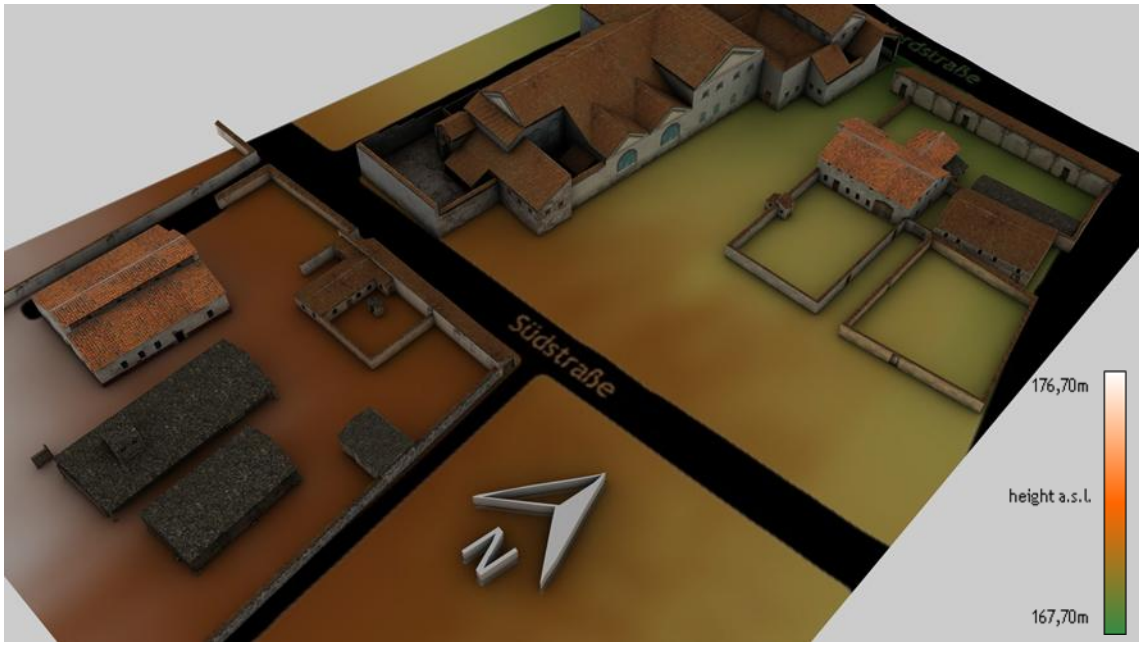

Fig. 12 – Textured model of this building period; based on terrain model with height references (Liv|in' Past 2011).

To conclude: Based on evidence from the Roman civilian town of Carnuntum we have tried to figure out the complexity of the archaeological record in an urban context, concentrating on a short period compared to the city’s history of over 300 years. Regarding the two theoretical concepts from which we have departed – the „Image of the City“ and urban „Eigenlogik“ – this enormous complexity should be taken as a strong argument for being more cautious in the elaboration of 3D-models and visualisations. In our point of view it is crucial to pay attention to three structurally different categories: 1) the aspect of space, containing the topography and fabric of a city; 2) the aspect of time, containing both transformation and continuity without the total concentration on one or the other; and 3) the aspect of human action and perception as well as material qualities of topography and buildings, connecting aspects 1) and 2). The importance of this last aspect can only be assessed by reconstructing the material remains of the respective urban area.
In our paper we tried to show that the system „City“ must always be conceived in terms of complex relations and may never be reduced to a single „time-slice“ by archaeologists and historians. The analysis and reconstructive visualisation of prospection data is potentially misleading because of the abundance of spatial information without proper chronological differentiation, perceptual analysis or functional evidence. On the other hand, isolated excavation without further prospection will remain on a micro-level of historical interpretation. Extrapolating from such kind of segmentary knowledge must always be highly speculative. Concerning the matter of changing urban perception it needs to be stated once again that this aspect cannot be convincingly illustrated by models chosen with regard to a single historical period or moment. As historians and archaeologists we should rather try to focus on the reconstuction and visualisation of diachronic change. However, as we hopefully succeeded to show, this kind of work can just be achieved by a thorough, combined analysis of prospection-data and excavation-results leading to a four-dimensional virtual reconstruction.

Fig. 13 – Textured scene showing stage 3 from looking south (Liv|in’ Past 2011).

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New Aspects of Urbanism in Grumentum

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Italy

Abstract: Several archaeologists, who studied and excavated at the Roman city Grumentum (in today’s area of Basilicata) mutually provided urban and territorial data for the first time. The aim of this was to develop a better urban map of Grumentum. Until now because of the absence of broad data it was only possible to present speculative reconstructions. This situation has changed in the last few years: extensive magnetic and electrical surveys, georadar, airphoto analysis, territorial surveys, reprocessing and historical analysis of former excavations, a huge bundle of new archaeological excavations and, last but not least, the use of the best modern technical possibilities help to create a new and more exact idea about the urbanity and territory of a nearly 1000 years populated Roman city that is well-preserved and has never been overbuilt despite its big territory.

A new starting point for questions regarding urbanity and territory is given by the joining of the data of different scientists and projects. A long lost and misunderstood Roman city becomes an outstanding example in Roman research.

This contribution to the conference tries to present the new findings and the way to these.

Keywords: Prospection, Roman cities, territorial survey, Roman urbanism.

Grumentum. Excavations of the University of Verona

For the past seven years the University of Verona has continued to carry out the excavation in the Roman town of Grumentum, under the direction of Prof. Attilio Mastrocinque.

The areas excavated are concentrated around the Forum. In particular excavations have been carried out on the remains of two temples, one north, the other south of the Forum, identified as Capitolium and Caesareum respectively. Since 2007 a circular temple has been investigated.

The area south of the Caesareum produced a complete stratigraphy. In the most deep layers also black figure Attic ceramic and local archaic ceramics have been found. A layer of the 1st century AD was rich in remains of a large meal, probably a cultic one (Cf. MASTROCINQUE et al. 2010: 1–7).

Excavations in the areas of Caesareum and Capitol allowed us to recognize a series of pavements of the Forum square which preceded the stone pavement of the middle of 1st century B.C. They were made of compact earth, small pebbles and very few mortar. The first pavement was laid in about the middle of the 1st century BC, a period in which the colony of Grumentum was founded, under the influence of the agrarian reforms of Caesar (MASTROCINQUE 2007; on the pavements MALACRINO 2008; FUSCO et al. 2009).

The round temple is located close to the Capitol, outside of the Forum, and its staircase looks North-East. It is preceded by an altar. Only the podium is preserved. It had no central cella, but only a circular structure, over which the cultic statue was placed. It could have been either a monopteros or a pseudo-peripteros, but the first hypothesis seems to be more probable. The surveys with magnetometer revealed the Southern part

of a wall which flanked the monument, and in 2011 two columns come to light between the Capitol and this temple. In the late phases of the Roman city a kiln for lime was discovered within the Capitol, in a partially destroyed part. Remains of smelting works were discovered South-East of the Caesareum. Ceramic sherds from the round temple allowed to date the end of the life in this area at the beginning of the 9th century.

Fig. 1 – Prospections.

Fig. 2 – Areal image of the forum.

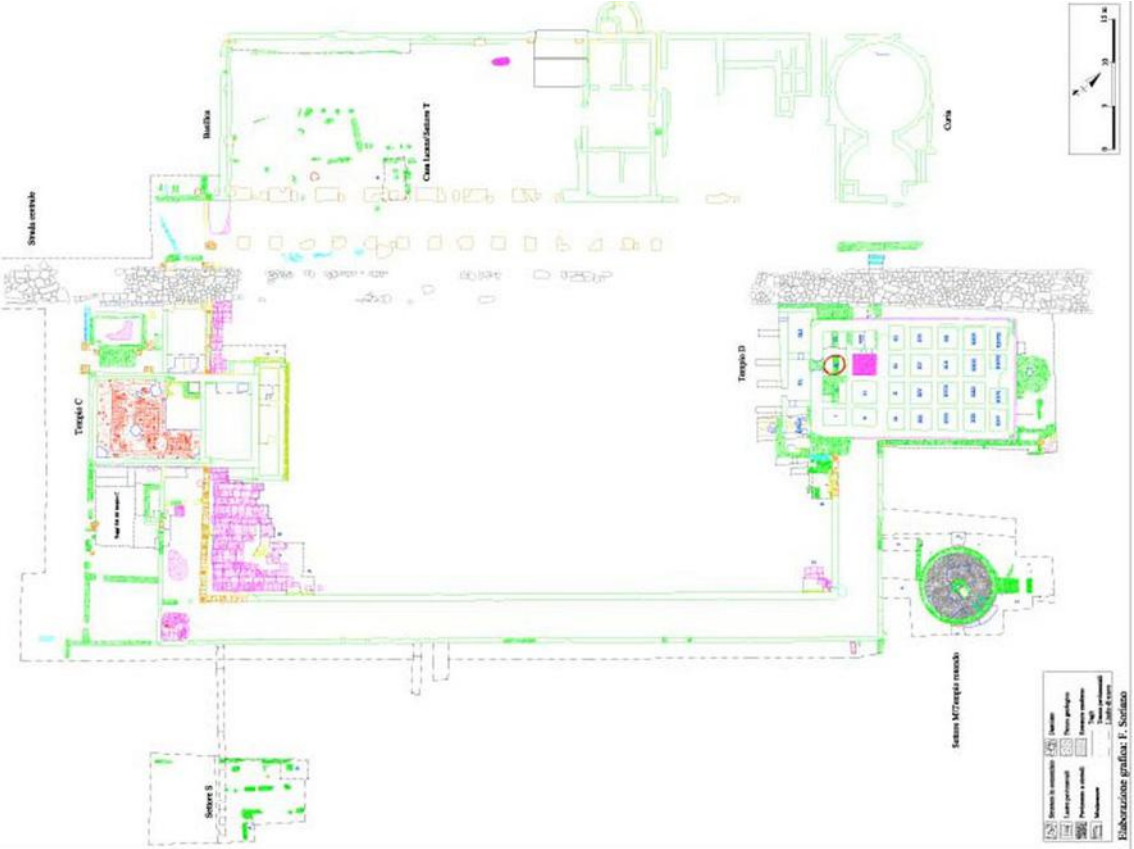

Fig. 3 – Map of the forum.

The different sectors of the Forum has been investigated by the following archaeologists: Federica Candelato, Ugo Fusco, Carmelo Malacrino, Lara Pozzan, Massimo Saracino, Vincenzo Scalfari, Fiammetta Soriano. A large team of young scholars have been engaged in the study of the different finds: Silvia Baschirotto, Giulia Bison, Dario Calomino, Lianka Camerlengo, Barbara Lepri, Chiara Marchetti, Teresa Perretti, Myriam Pilutti Namer, Marianna Scapini, Rossana Scavone, Elisa Tomasella. An équipe directed by prof. Francesco Guerra (Architecture University of Venice) realized plans, sections, aerial ortho-photographs, 3D models of parts of the Roman city.

Magnetometry at Grumentum

Since 2005 the University of Verona carried out archaeological researches on the Roman Forum of Grumentum (MASTROCINQUE 2007; on the pavements MALACRINO 2008; FUSCO et al. 2009). Since 2006 prospections with different methodologies have been done thanks to dr. Ermanno Finzi, Marcello Ciminale, Maurizio Gualtieri and Tommaso Mattioli. We present now only the results of measurements in the latest two years with a Geoscan FM256 Fluxgate Gradiometer. They have been done by Attilio Mastrocinque and Fabio Saggioro of the University of Verona.

The surface has been scanned every 50 cm, with grids of different extent, with single traverses, using a medium sensibility (1 nanotesla). Only the Forum’smain square has been scanned at 0,10 nanotesla. The area covered with each survey is about 2 hectares. After measurement, data have been corrected for common surveying problems and for a clearer viewing, using Geoplot 3.0, Arc GIS 9.3 and Adobe Photoshop CS2.

Fig. 4 – Prospections.

We describe the most noticeable grids. The survey no.1 shows traces of small rooms, but the presence of underground electric wires disturbed the measurements.

South-West of the square and of the Caesareum the survey no.2 shows a series of rooms, corridors, and perhaps small square courtyards which are supposed parts of two or three Roman *domus.* An impressive anomaly close to the end of our prospections has the form of an irregular line, ca. 50 m long. It has a strong polarization whose direction does not coincide with the earthly North. Only an excavation can show the exact nature of this magnetic anomaly, but we may put forward the hypothesis that it is a lead pipe, or *fistula*.
Closer to the Caesareum the survey no.3 shows a series of square rooms; they could be a series of shops aligned to one NE-SW street, and perpendicular to the so-called *decumanus*. Their doors appear to be opened to NE.
The measurements on the Roman square (survey no.4) show a rectangular structure, perhaps a monumental base, in front of the Caesareum, on its eastern part. A clear long line runs at 7 m from the porch, with the same alignment. An excavation is necessary to understand its nature. As a provisory hypothesis we can suppose that it is a more ancient base of a columnated aisle of the eastern porch. If this hypothesis could prove true, the first Forum should be smaller than the extanding.
The field which lays eastwards of the Forum has been investigated with many methodologies, but magnetometry has proved the most suitable. Measurements done by M.Ciminale and M.Finzi showed a series of rooms of the same form, aligned with the long side of the Forum. An excavation has been done in the Southern part of the investigated area and several rooms appeared, aligned with a long wall, which runs parallel to the Forum. Our survey no.5 shows a series of rooms and other structures, among which also the dug wall. The field near the outer wall of the Forum does not appear to have buildings. A long kiln was detected close to the Forum’s wall by Ciminale and Finzi and partially excavated in 2007. It was situated at a high layer and presented no pottery finds inside.

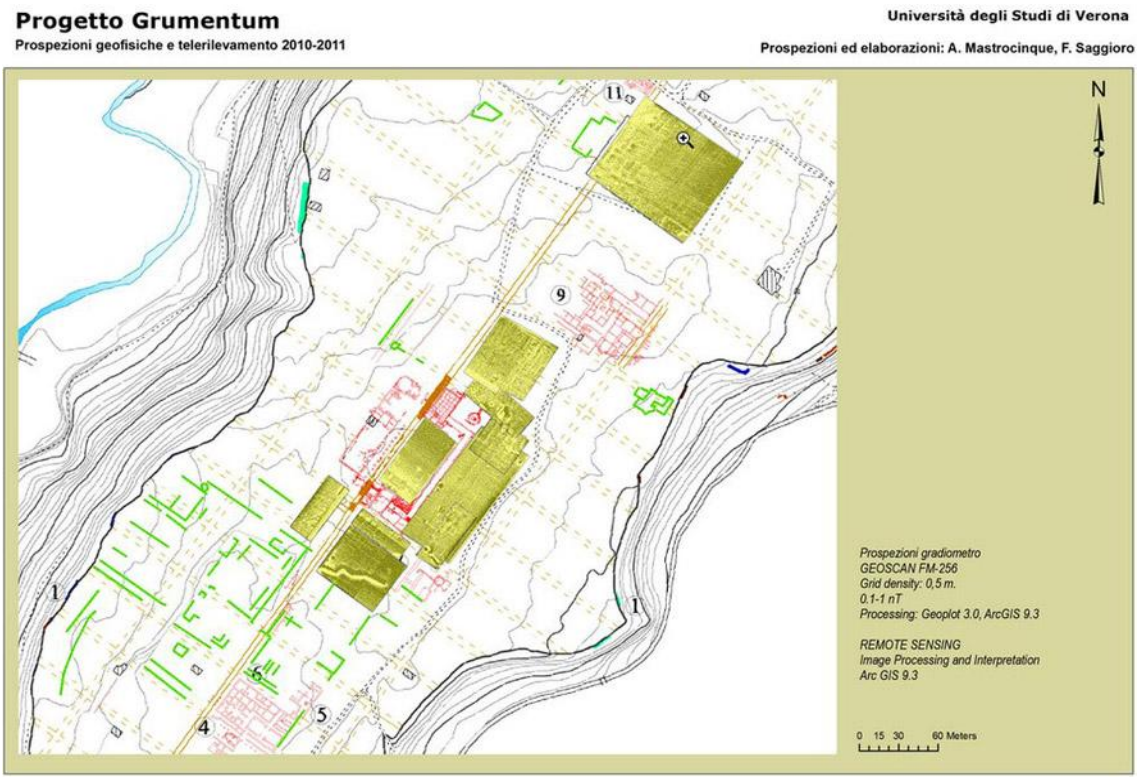

Fig. 5 – Map of prospections.

Survey no.6 shows the L-shaped line of the outer wall which surrounded three sides of the round temple. Recent excavations proved that the other side of this wall had been erased when the Capitol was built (at the middle of the 1st century AD), and columns stood right and left of the temple.

Fig. 6 – Maps of prospections.

Survey no.7 was disturbed by many factors and does not show anything important.
Going northwards, the 50x50 m survey no.8 has detected a large part of an important *domus*. The iron fence prevented us to investigate the adjacent areas. The western part of the survey showed nothing evident, because of the modern path which covers the ground.
A large area near the church of S.Maria Assunta has been investigated by survey no.9. At NW (left in the image) one can see the main street (or “*decumanus*”) and two large buildings close to the street. They are divided inside by internal walls. Another rectangular building is visible at the southern corner of the prospection, which could not go forth in this direction because of a concrete base and a mound. A series of lines is visible at the centre of the survey. Their direction does not correspond to the main orientation of the city ways and *insulae*.

(A. M./F. S.)

Urbanistic evidences in excavation project

The situation

Grumentum is a Roman city of 40 hectares and positioned on a large bluff oriented NW-SE overlooking the Agri river in the province of Basilicata in the south of Italy (THALER and ZSCHÄTZSCH 2005; THALER 2009). The city is thought to have been founded in the early 3rd century BC as part of to control to the wealthy costal cities of Magna Graecia. It was destroyed by the social wars (92-83, BC), and re-founded in last decades before of the first century BC. It reached its’ apogee in the Early Imperial period and later declined into obscurity in the 4th and 5th Centuries AD. In the early medieval period the site was levelled and has been used for agricultural purposes until the present day.
The current project is an investigation of the urban fabric of the city in all periods, focusing on three areas, the Amphitheatre, the Decumanii and the Imperial Baths.
The archaeology of state-level societies is a massive undertaking and Roman cities such as Grumentum are typical in this case. To understand the layout of the City, a large area has been excavated and this has produced large numbers of artfacts and a huge amount of archaeological documentation consisting of strata descriptions, maps, photographs and other forms of documentation familiar to any form of archaeology. In addition, the excavated structures themselves require special treatment. Each wall and architectural feature must be photogrammetrically documented, measured and restored, and then placed within a sequence of rebuilding and use over the course of 800 years. Along this, there are minor structures such as canals, sidewalks and porticii that need be taken into account when studying the Roman city.
When dealing with a massive structure like a Roman Amphitheatre, the documentation alone can take a field season. Hence the analysis of the physical remains of the excavated structures is enough to provide generations of research. To create a meaningful archaeological narrative from this amount of data, a life time work would have been done in the past been.

Fig. 7 – Grumentum, google map.

Fig. 8 – Urbanistic rendering.

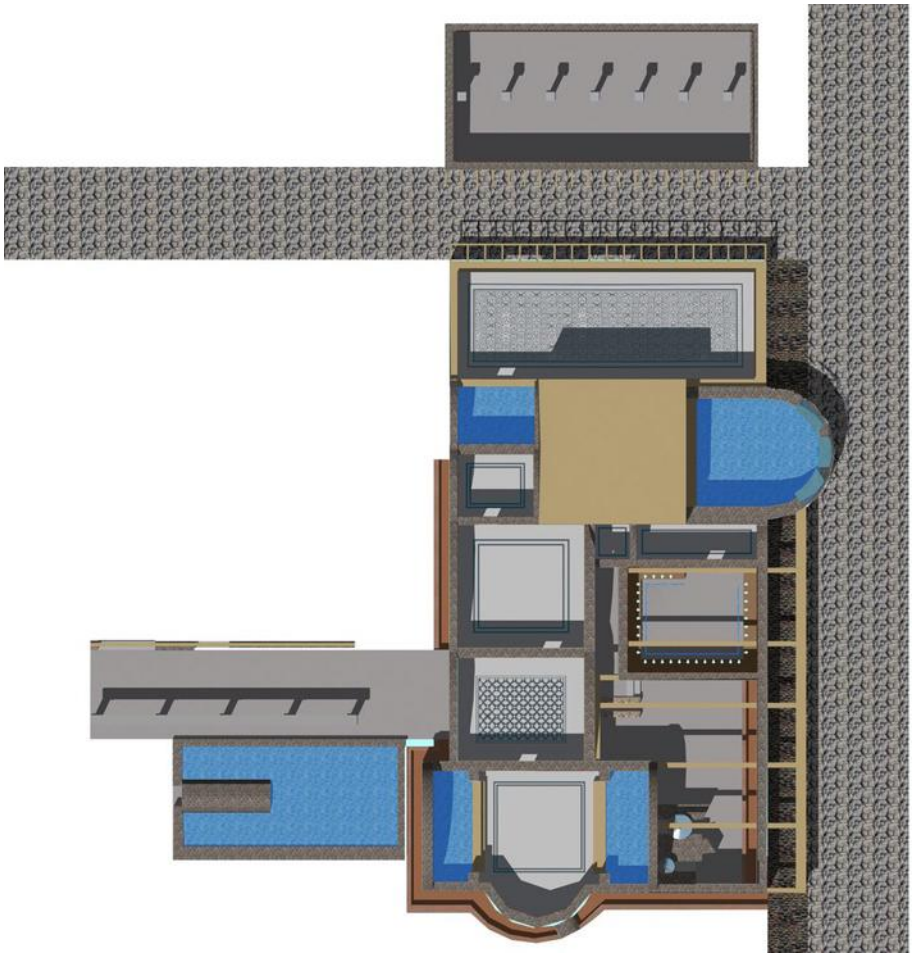

Fig. 9 – Reconstruction of the imperial Baths.

The excavations have traced a spatial shift in the organization of the city that mirrors the historic changes from Imperial to Late Antique times. Numismatic and ceramic evidence indicates the gradual abandonment of the southern decumanus and the clustering of settlement along the northern one. Along one *cardo*, a series of walls were found straddling the road, cutting the connection between the *decumani*. Nearby, a villa connected to the *cardo* but cut from the north *decumanus*, by the walls, was abandoned and destroyed (fig. 6). This decline is well illustrated by the archaeological sequence of the baths. There, after several phases of reconstruction, it was abandoned and used as a garbage dump. However, the archaeology indicates that this decline was not a continuous process. The north decumani was resurfaced in Severian times indicating the revival of the cities fortunes in this period. Post-roman settlement has been found in the area of the baths and includes hearths, post-holes, architectural remains and a necropolis. The necropolis consists of inhumation burials in and around the baths of numerous individuals. They consist of both single, and double burials that have been genetically identified as Lombards, a Germanic tribe that entered Italy in the 7th century A.D.

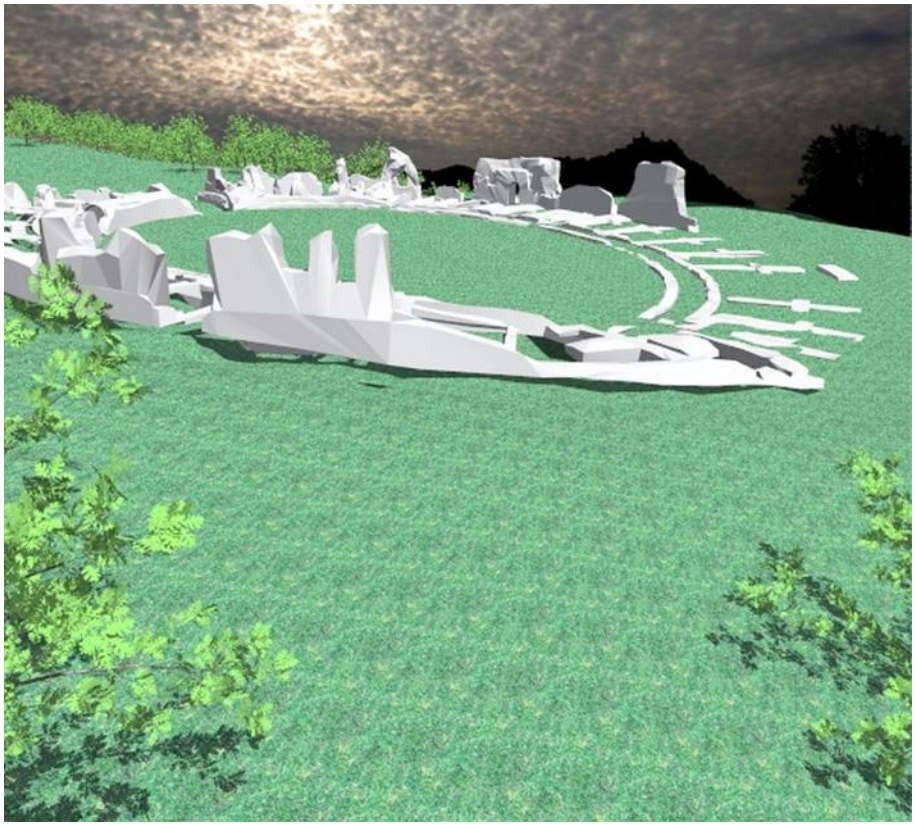

Fig. 10 – Rendering of amphitheater.

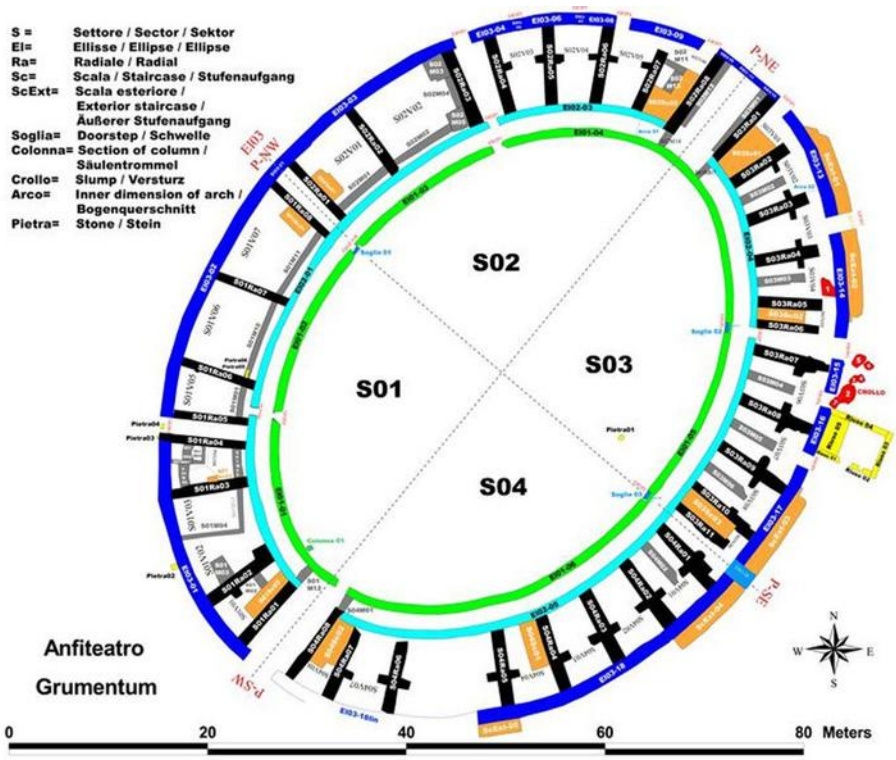

Fig. 11 – Map of amphitheater.

Fig. 12 – Excavation of decumanus.

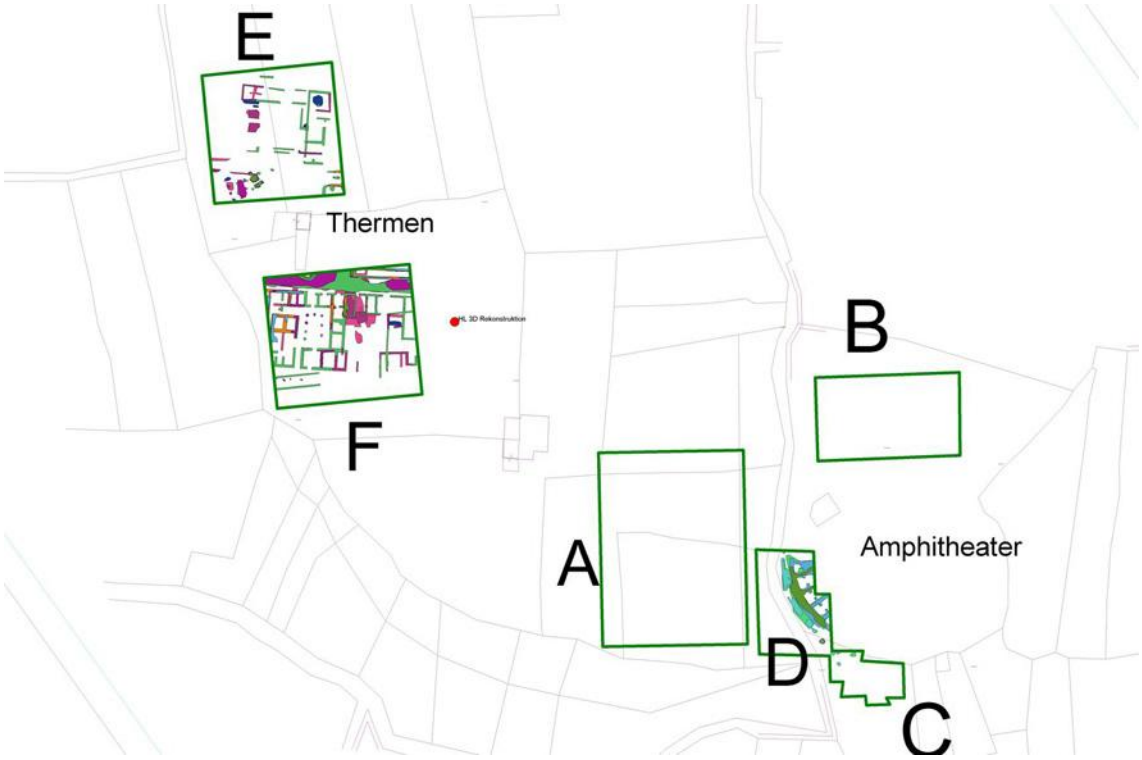

Fig. 13 – Area of prospections.

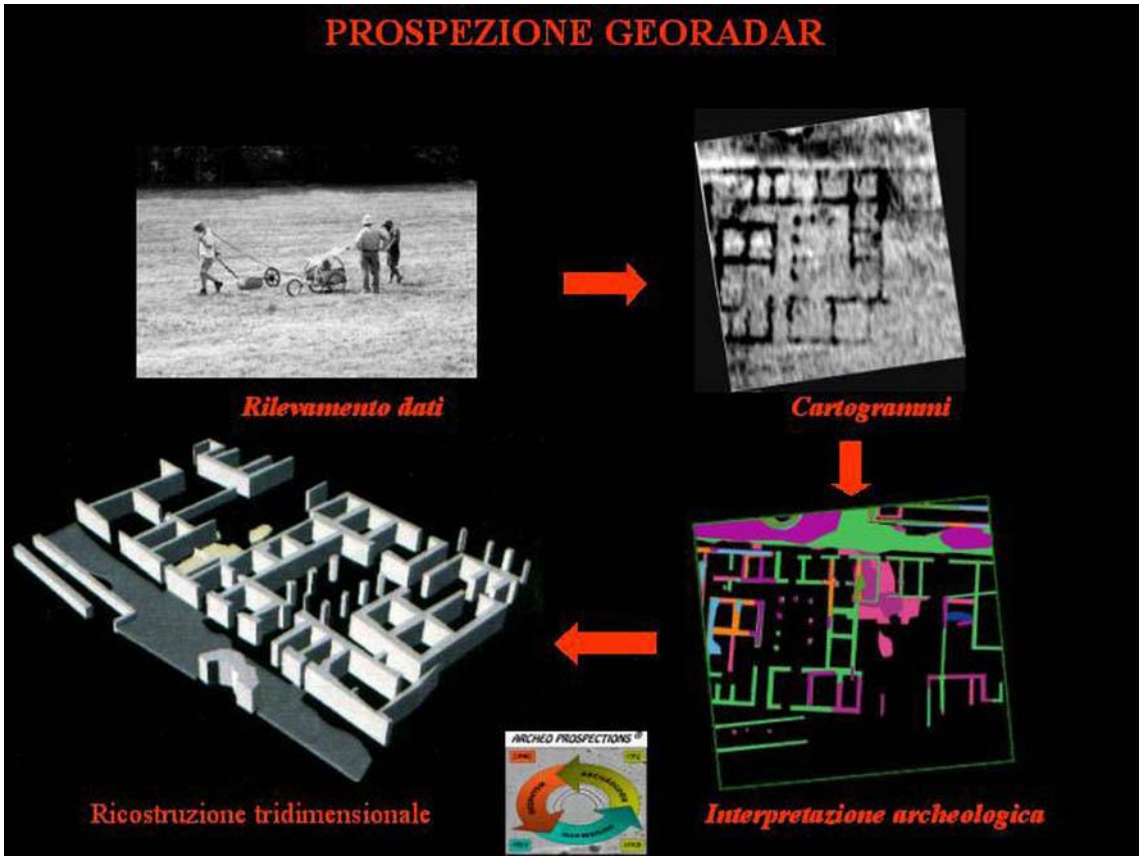

Fig. 14 – Datatypes of georadar prospections.

Geophysical survey

In 1999 a series of Geo-Radar surveys were performed by Archaeo-Prospections of Vienna (NEUBAUER 1999; THALER and WATSON 2003) around the Amphitheatre and in the area of the Imperial Baths. The survey results were presented as raster and shapefile data as well as the more traditional image data. These raster datasets allow us to compare the original interpretation with actual archaeology by superimposing the plans. This comparison provides us with a means to judge the effectiveness of the technique, and has validated it (fig. 5). Also, by providing an interpretation as shapefile in 10cm slices, the geophysical data has proven useful in targeting anomalies. In this capacity, for instance, it has been especially helpful for locating the locations of mosaic floors.

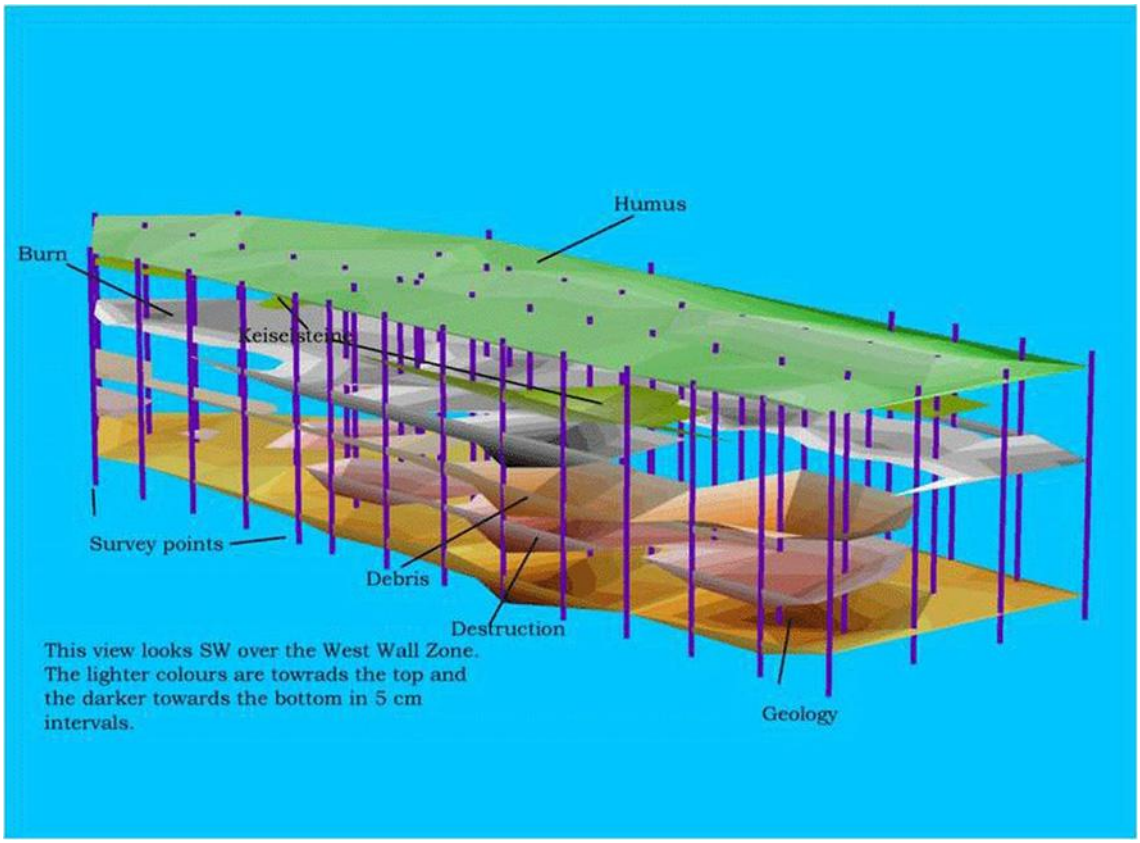

Fig. 15 – Cre-prospections.

Local survey

In many cases it is neither necessary nor possible to excavate a room. In these cases we have experimented with the use of an Excalibur probe (basically a large, hammer-driven borer) to sink a series of cores across the room to intersect the layers. The surfaces of the layers are recorded on site and the points are spaced sequentially at regular intervals (usually 50cm or 1m). The line of the cores is then recorded by a total station. Later, using ArcView, GIS the lines are imported from the co-ordinates and the recorded points are digitised as a multipoint theme. In the database file of this theme the depth below the surface of each layer is recorded. From this dbf a three dimensional surface can be created for layer. When viewed in ArcScene, these layers can be either separated for clarity (fig) or grouped together for a more naturalistic reconstruction.

(H. Th.)

Conclusion

Putting together the excavations and different prospectionsdata we have following urbanistic map of Grumentum at the end of 2011:

Fig. 16 – Urbanistic map of Grumentum, end of 2011.

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