

Postersession

Documenting Venetian and Ottoman landscape in Crete: Settlement patterns, road network and productive areas in Rethymnon inland

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Abstract: The region under study is located south of the town of Rethymnon. An exploratory survey of the region was focused on the architectural remains (settlements, churches, secular buildings) in a chronological frame from the Late Antiquity to the Late Ottoman Period on to the days of Cretan Policy (Autonomy). Archaeological data were registered in a relational database (MS Access software) assembling conceptual fields for topographic, architectural and morphological information. The database was integrated in a Geographical Information System consisting of various environmental and topographic layers for the better spatial analysis of the sites and monuments. Slope and cost-surface maps were created and GIS analytical tools were used for visualizing the evolution of settlement patterns, as well as for reconstructing the road network and defining the productive areas (watermills, vineyards, arable land, terraces and pasture regions) in cross-correlation to the written sources and archives. This effort provides a cultural heritage tool for the local Archaeological Service as well as the IMS/Forth Digital Archaeological Atlas of Crete in the web. Also, the reconstruction of the former road network gives the opportunity to unify the various late medieval and pre-modern monuments with their landscape and cultural context via new accessible paths.

Keywords: Settlement patterns, road network, productive areas, cultural heritage, Crete.

Introduction

The region under study is located south of the town of Rethymnon, within the limits of the former Rethymnon province and the now homonymous municipality, which includes different geomorphologic subdivisions (lowland, hilly and mountainous terrains) (Fig. 1).



Fig. 1 – Map of Crete and the area of interest.

The area has been poorly surveyed compared to other regions of Crete and only some prominent monuments were mentioned by GEROLA (1905-1932). An exploratory survey of the region identified a number of architectural remains (settlements, churches, secular buildings) which were considered as distinct sites covering the chronological frame from the Late Antiquity to the Late Ottoman Period and the days of Cretan Policy (Autonomy).

Objectives & Methodology

The goal of the survey was to recognize and record the archaeological sites of the region in an effort to study the architectural context of the monuments in relation to the natural and human landscape evolution and at the same time to provide a guide for the preservation of cultural heritage resources in a rapidly developing environment. The research questions were focused to the definition of the settlement patterns, the organization of the economic / productive areas around the settlements in the context of the natural environment and the reconstruction of the road network which connected the settlements and the town of Rethymnon with the southern inland and coastline (CHARITOPOULOS 2009).

Archaeological data were registered in a relational database (MS Access software) assembling conceptual fields for topographic, architectural and morphological information. The conceptual design was based in the CIDOC standard having the necessary requirements for the nature of veneto-cretan architectural remains documentation (BARBER 1999, QUINE 1999). The records concerned site's name and topography, geographical coordinates in the Greek Georeference System [ΕΓΣΑ '87], site's type and size, a brief site description, architectural phases, preservation condition, dating and written sources documentation. The database was integrated in a Geographical Information System consisting of various environmental and topographic layers for the better spatial analysis of the sites and monuments.

Analysis

A Geographic Information System archive was made in order to manipulate, visualize and analyze the archaeological data (CONNELLY & LAKE 2006). Thematic layers included aerial photos and topographical maps of the Greek Army Geographical Service and the Greek Ministry of Agricultural Development, as well as old Venetian maps for Rethymnon region of Fr. Basilicata and A. Oddi from the collection of the Gennadeius Library, American Archaeological School at Athens (CHRYSOCHOOU 2001). The above maps were overlaid on digital thematic maps related to the geographic and geomorphologic attributes of the region, such as slope, cost-surface, geological formations, a.o.

GIS analytical tools were used for visualizing the evolution of settlement patterns, as well as for reconstructing the road network and defining the productive areas (watermills, vineyards, arable land, terraces and pasture regions) around the sites in cross-correlation to the written sources and archives. Architectural remains were examined in four main environmental factors, namely topography, geology, soil and water resources (DOXIADIS 1968), in order to justify the specific choice of building construction and relate the architecture with natural environment.

The settlement pattern of the surveyed region was cross-correlated with a venetian census of 1583, published by the venetian officer Kastrophylaka, ottoman cadastrals of early ottoman years (1658-1659) and

a census of the late ottoman period, published by Stavrakes in 1890 (STAVRAKES 1890, SPANAKES 1991) (Fig. 2).

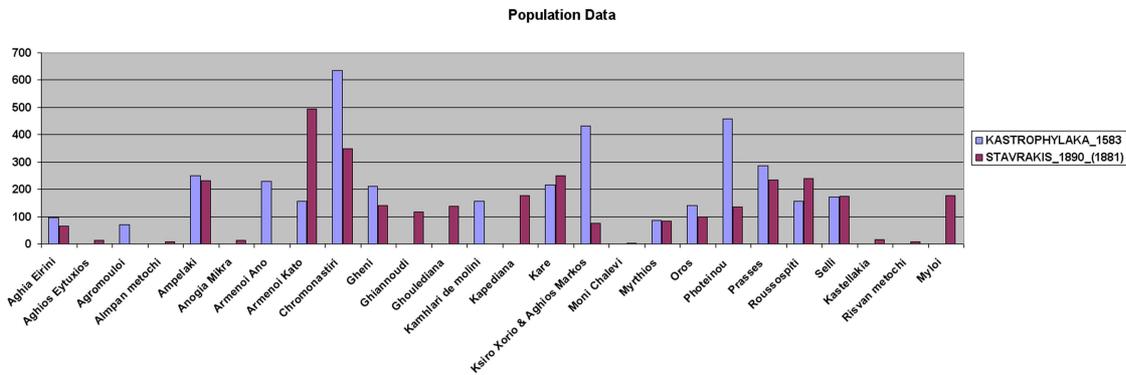


Fig. 2 – Chart of the settlements and their population in 16th and 19th century .

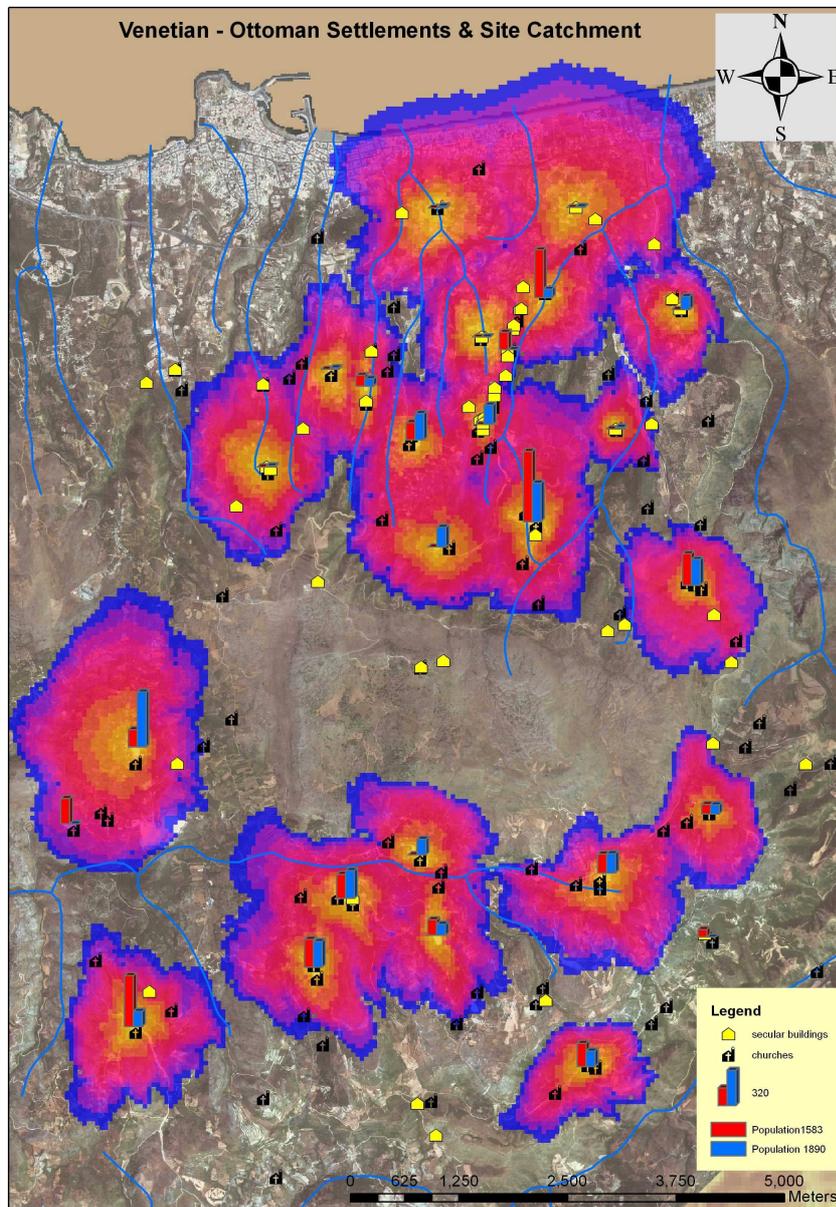


Fig. 3 – Venetian & Ottoman settlements and their corresponding site catchment.

The buffers were linked with the freestanding churches in the cretan landscape, since they usually define places of economical activities, crossroads and landmarks (NIXON 2006).

The road network was reconstructed using both sections of existing remains and the archaeological context and least cost path analysis tools (BOMMELJÉ & DOORN 1996) (Fig. 4).

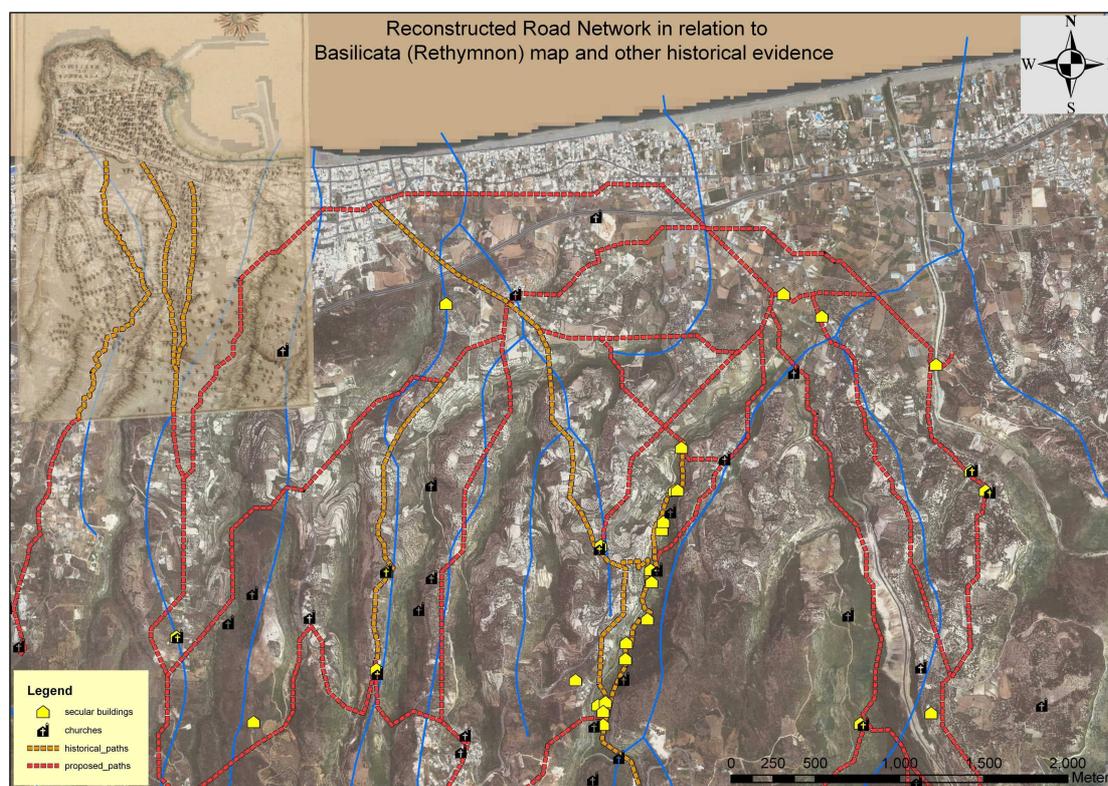


Fig. 4 – Reconstructed road network in the northern part of the area of interest.

The existing remains consisted of stone-paved or cut-in-rock roads (*kaldherimia* / *καλντερμία*), bridges and simple paths in valleys which connected the northern coastline with the southern mainland. The archaeological context included settlements where roads were passing from, productive areas like watermills and freestanding churches. The analysis was supported in cross-correlation with written sources. For the urban center of Rethymnon and its suburbs, two late Venetian maps (of Fr. Basilicata and A. Oddi) provided very useful information depicting the existing road network of that period. These maps were rectified and they were used as the basic layer for reconstructing the expanding road network.

Results

Having related the settlement patterns with the productive zones it was possible to evaluate the different usage of the architectural remains and its evolution in the transition from late Venetian to late Ottoman period and its implication to early modern times development in Crete.

The majority of the settlements remained in use from Venetian to Ottoman period surviving till today. Some of them were abandoned in the late ottoman period. The settlement pattern consisted of villages, mainly small, and even smaller hamlets numbering a few rural houses or one rural villa which are named in Crete *metochia* (μετόχια). In the settlement pattern we can add the monasteries which were also inhabited and had

a significant economic role in the region. Villages were located in the mountainous regions, in narrow ridges between small valleys or inside the valleys in main passages to the interior of the island. The geomorphological settings of the village's location specified also its type in terms of the architectural plan. Villages constructed in the ridges had a castle-like appearance, as a core, having rings of houses built tightly one beside the other, like a kind of a walled enclosure (Fig. 5, 6).



Fig. 5 – Kapediana village.



Fig. 6 – Chromonastiri village.

On the other hand, villages located at the passages had their houses scattered around the main route in a linear manner. A small number of villages host free standing houses, which can be justified either due to their habitation during the later times or to their early abandonment. Similar kind of architectural attributes with free standing structures is also exhibited by *metochia*. Monasteries and large rural villas displayed distinctive castle-like formation having an enclosure or a tower kind building.

The majority of the settlements were easily accessed by a corresponding road network. Arable and pasture lands existed in their vicinity, which together with the close-by water resources guaranteed the sustainability of the economic growth of the villages. The economic zone of each settlement consisted of fields for small scale agriculture and pasturage, as well as watermills, oil and wine presses and threshing-floors, all in arable plain lands or terraces in mountainous areas below the limit of 600-700 meters altitude (Fig. 7).

In the mountainside, the arable land increased significantly with the terrace formation. Terraces were used for cultivation (mainly cereals, vines and oil trees) and they provided an additional countermeasure against the erosion caused by rainfalls. Freestanding churches were found to be located within the economic buffer zones usually designating a landmark for productive areas (RACKHAM & MOODY 1996, NIXON 2006).

The road network used the geomorphology of the landscape, passing by small valleys south of Rethymnon town and following smooth elevation contours in order to access the mountainous and semi-mountainous areas, making accessible even the difficult, rocky terrain. For this reason, rock-cut and terraced paths along with bridges were constructed in appropriate places, some of which are obvious even today (Fig. 8).

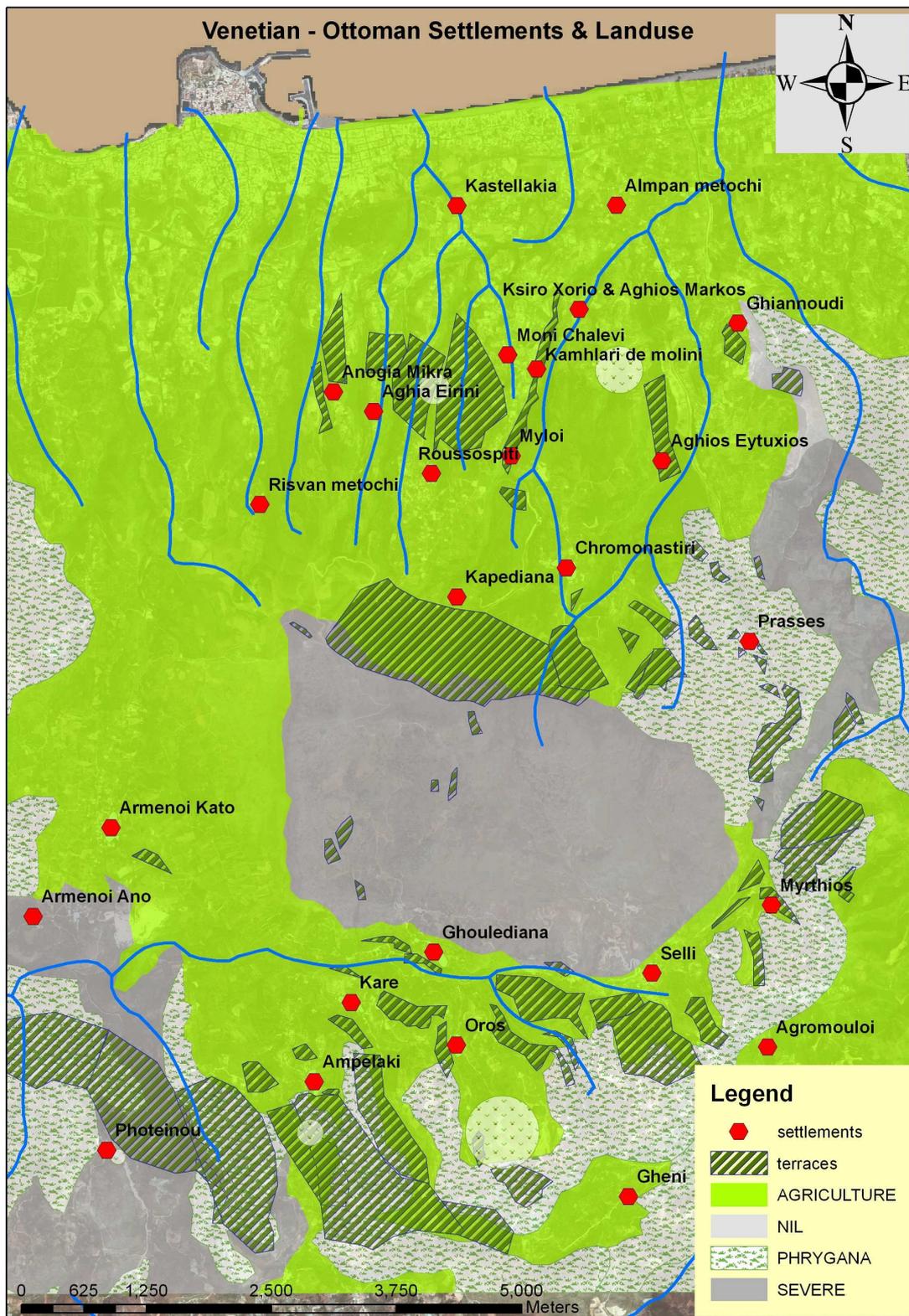


Fig. 7 – Venetian - Ottoman Settlements and Landuse.

The most significant bridge in the region is a three-arched stone built, constructed during the first two decades of the 20th century above a steep ravine in the road from Rethymnon to the highlands of Amari on the eastern part of Psiloreitis mountain (Fig. 9).



Fig. 8 – Rock-cut and terraced path (kaldherimi).

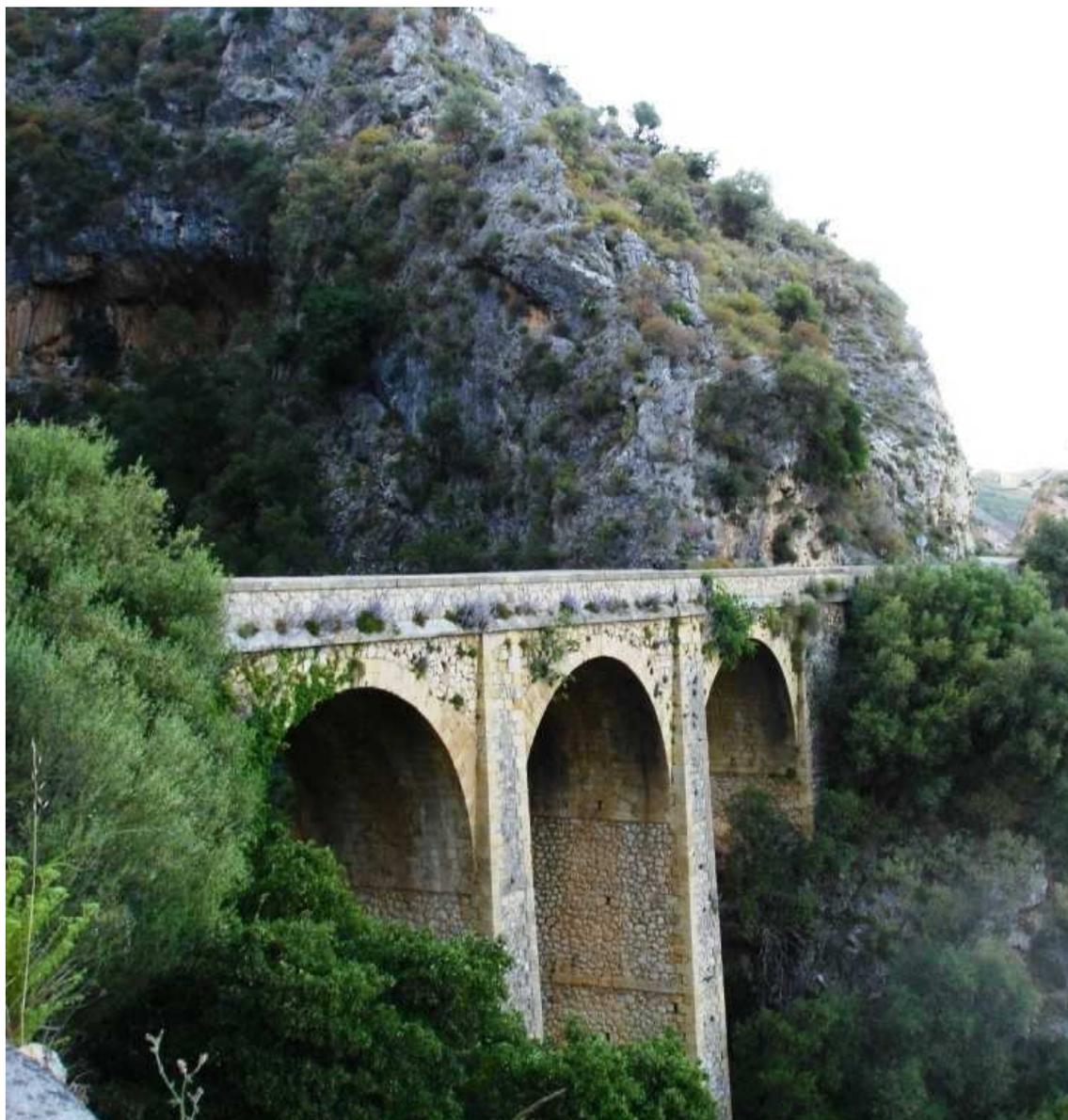


Fig. 9 – The three arched bridge located along the road connecting Amari highlands with Rethymnon.

Conclusion

The spatial processing of the archaeological database resulted a well defined reconstruction of the settlement patterns spanning from the early Venetian to late Ottoman period, offering a way of unification of the various late medieval and pre-modern monuments with their landscape and cultural context. The above data enriched the IMS/FORTH's Archaeological Atlas of Digital Crete project and they can be further exploited by the local Archaeological Service for the better preservation and protection of the cultural heritage. At the same time, this project has also tourist implications, since the particular paths and monuments can be used as itineraries for visitors and researchers.

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Archiving the Archaeological Heritage in the Brussels Capital Region, Belgium – A Challenge for the Future

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Abstract: The Heritage Information and Management System of the archaeological department of the Heritage Direction of the Brussels Capital Region combines excavation information, laboratory restorations and storage room management. It is functioning within a Microsoft Office Access 2000 environment and is housed on the central server of the Direction. It consists of a front-end holding the interface and a back-end holding the actual data, thus allowing a multi-user environment. The structure consists of various tables, linked by relationships one-to-one and one-to-many. It covers all archaeological actions, from the excavation, through the analysis of deposits and the inventory and study of the various objects, to the final storage of the objects, the samples and the digital and non-digital excavation information. The combined input into one database of elaborate scientific archaeological information and laboratory and archival managing tools thus guarantees access for future generations of researchers.

Keywords: Database, archiving, digital documentation, archaeological heritage, depot management

Introduction

Since 1989, archaeological heritage is a regional competence in the federal state of Belgium. Each region (the Flemish, the Walloon and the Brussels Capital region) has thus its own specific archaeological decrees and working methods (DRAYE, MATTHYS & DEMETER, 2005).

The inventory of the archaeological excavations in the Brussels Capital Region, is realized with the help of a database, created in the year 2000. This database was inspired by the results of a project initiated by the Flemish Community on standards for the registration of archaeological objects in a museum context (DRIESEN, WESEMAEL & ARON bvba 2001). Today, the database has evolved into an Archaeological Heritage Information and Management System combining research with archaeological storage management. It is founded on the registration of the various discoveries in their archaeological contexts for every site excavated within the Region. This implies a continuously carefully thought out structure for the different levels of information regarding the excavations (site information, stratigraphic units, description of objects), the treatment of the objects (e.g. various restoration procedures) and the management of the storage. Therefore, the input of the archaeological data has to be clear and precise, as a correct registration constitutes the base of an accurate conservation and user-friendly consultation.

The structure

The database has been developed in Microsoft Office Access 2000 and is housed on the central server of the Heritage Direction. It consists of a front-end holding the interface and a back-end holding the actual data, thus allowing a multi-user environment. Various tables are linked by relationships one-to-one or one-to-

many. In order to reduce as much as possible human errors upon entry of the data, most fields consist of scrollable lists or clickable squares and the unique object numbers appear automatically in related sub-fields.

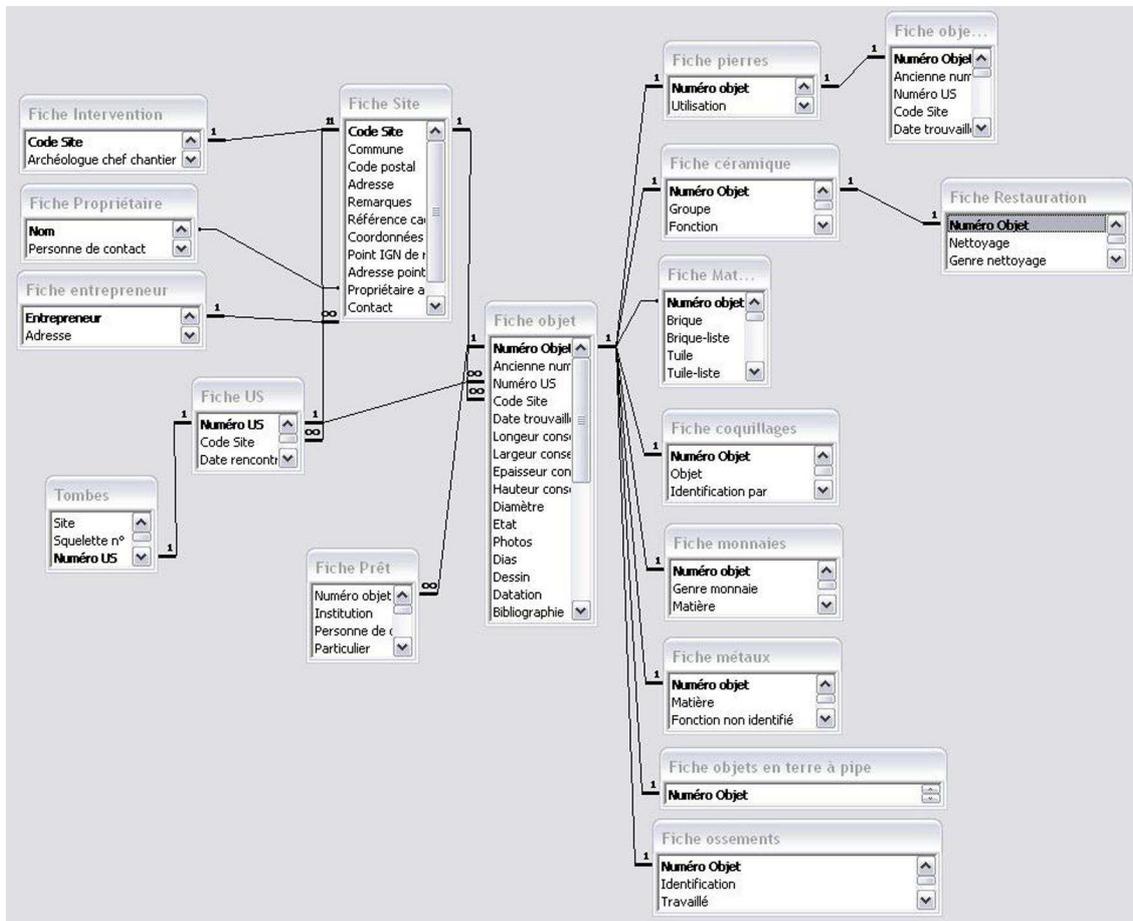


Fig. 1 – Part of the structure of the Brussels Archaeological Heritage Information and Management System (© MRBC-DMS)

Continuous feedback and regular evaluations create the necessary permanent evolution of the database's potential (activation of new fields and queries, completing of the scrollable lists, etc.). Data-input is organized for each level of responsibility, from the workman via the laboratory assistant to the archaeologist. Regular control operations guarantee the quality of the input.

The archaeological site

The data-input starts with the archaeological site information. In the Brussels Capital Region, each archaeological site receives a code composed of two letters, indicating the commune concerned, and a number from 1 to n per commune. E.g. BR045 = commune of Brussels, rue de Laeken nrs. 73-75, the so-called house of the 18th century architect Laurent-Benoît Dewez.



Fig. 2 - Excavations in the courtyard of the 18th century house of architect Laurent-Benoît Dewez (© MRBC-DMS)

The site form contains a range of fields identifying the archaeological site with its code, address, cadastral references and GIS coordinates. The names of the proprietor of the land / building and of the building contractor are linked to a sub-file holding all contact information. The Intervention Form contains the dates of the archaeological excavation and the names of the persons that participated: archaeologists, technicians, workmen, trainees.

Fiche US

Número US: BR100/0090	Date rencontre: 30/05/2005	Objets Site Tombes ▶* Image: <input type="text"/> <input type="button" value="↩"/>													
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Os humains	Bois														
Métaux	Cuir, étoffe														
Verre	Monnaie														
Terre à pipe	Pipes														

Fig. 3 – The Stratigraphic Units Form (© MRBC-DMS)

The input continues with the Stratigraphic Units Form detailing the information concerning the various stratigraphic layers encountered during the excavations. Each unit is composed of the site code followed by a number from 1 to n (e.g. BR059/023 = stratigraphic unit 23 of site BR059). The form contains, next to the unit number, its location on the site, the type of layer (e.g. a soil, the filling of a pit, etc.), its texture (sand, clay, silt, etc.) and the links with other stratigraphic units. In the case of a constructed stratigraphic unit, the form includes a description concerning the type of construction (wall, foundation, staircase,...), its elements (bricks, quarry-stones,...) and their size, the mortar used, its color and the jointing. A first general description of the various categories of objects found in the layer is also included. A button gives access to the detailed report concerning the various analyses of the layers (archaeopedological, physical, chemical, etc.). In a near future, the results of dating procedures, and archaeozoological and archaeobotanical research will be added.

The tombs are registered starting from the Stratigraphic Layer Form. The Tomb Form copies the same categories as used on the paper form in the field: skeleton number and associated stratigraphic unit, localization and orientation of the skeleton, the excavator, the list of pictures and drawings, the general position of the body and each body part, the preservation of bony tissue and of other elements (e.g. finger- and toe-nails), the eventually applied conservation techniques and objects found around the body. A button shows the detailed results of the palaeoanthropological analysis of the skeleton.

Fig. 4 – The Tomb Form (© MRBC-DMS)

Only when the Site Form and the Archaeological Unit Form are filled in, one can start recording the objects found during the excavations in the Object Form. Each object receives a unique number composed of the site code, followed by the stratigraphic unit number, followed by a number from 1 to n ; e.g.

BR045/187/00464 = object nr. 464 of site BR045 found in layer 187. The Object Form contains the general information on the object: category (ceramics, metal, etc.), its condition, dimensions, the drawings and pictures of the object, its publication and comparisons in literature.

Fiche Céramique

Numéro Objet:

Fonction:

Composants:

Matière:

Couleur pâte:

Code utilisé pâte:

Code couleur pâte:

Dégr végétaux:

Dégr minéraux:

Traces d'utilisation:

Utilisation secondaire:

Fabrication:

Fabrication remarques:

Marques:

Marque de propriété

Marque de potier

Marque de contenu

Origine:

Localisation:

Glaçure

Code utilisé Glaçure:

Glaçure extérieure:

Couleur Glaçure Extérieure:

Code Couleur GE:

Glaçure Intérieure:

Couleur Glaçure Intérieure:

Code Couleur GI:

Remarques:

Engobe

Code utilisé Engobe:

Engobe extérieur:

Couleur Engobe Extérieur:

Code Couleur EE:

Engobe Intérieur:

Couleur Engobe Intérieur:

Code couleur EI:

Remarques:

Fiche objet même numéro

Fiche Restauration

Traduction/Vertaling

Décor

Décor: **Couleur Décor:**

Décor produit par: **Code couleur décor:**

Emplacement Décor: **Code utilisé couleur décor:**

Description décor:

Fig. 5 - The Ceramics Form (© MRBC-DMS)

Starting from this general form, one has access to the sub-forms that incorporate information specific for each type of material. One clicks therefore on the appropriate button: ceramics, metal objects, glass objects, pipe-earthen objects, building materials and objects in organic materials (wood, ivory, etc.). The Ceramics Form e.g. has fields concerning the function and components of the object, its fabric, the presence of glazing, its decoration and provenance. The Metal Form describes, among other things, the nature of the various objects (needles, dress accessories, cutlery etc), the technique used and the assembling of the various parts.

Fiche monnaie			
Numéro objet:	<input type="text" value="BR042/019/00037"/>	Position de frappe:	<input type="text" value="9 heures"/>
Genre monnaie:	<input type="text" value="jeton de Saint Marc"/>	Lieu de frappe:	<input type="text" value="Nürnberg"/>
Matière:	<input type="text" value="bronze"/>	Date de frappe:	<input type="text" value="milieu du 16e siècle"/>
Condition:	<input type="text" value="bonne"/>	Pays:	<input type="text" value="Allemagne"/>
Poids:	<input type="text" value="6,61 g."/>	Souverain:	<input type="text" value="anonyme"/>
Description face:	<input type="text" value="lion de Saint Marc avec nimbe et livre tourné vers la gauche"/>		
Légende face:	<input type="text"/>		
Description revers:	<input type="text"/>		
Légende revers:	<input type="text"/>		
Identification par:	<input type="text" value="De Buyser Frans"/>		
Image:	<input type="text"/>		
<input type="button" value="Retour Fiche Objet"/>		<input type="button" value="↩"/>	<input type="button" value="Traduction/Vertaling"/>

Fig. 6 - The Coin Form (© MRBC-DMS)

The Coin Form has been separated from the Metal Form as it contains specific information like the type of coin, the material the coin is made of, its condition and weight, the period of minting and the sovereign concerned, and a description of the decoration and the legend. Another example is the Tobacco Pipe Form. Tobacco pipes will be found in large quantities starting from the 16th century. They require a specific description: the various parts of the pipe, the identifying marks and the decoration, the factory, etc. The Pipe-earthen Form includes the description of some peculiar objects like small painted round plates with religious and festive decoration and small statues of the “Child Jesus”. Both were used for decorating Eastern breads and are frequently found in excavations.

Fiche Restauration	
Numéro Objet: BR045/187/00464 Restaurateur: Nachid Nadia	Date de restauration: 24/04/2008 Laboratoire: MRBC-CCN-S.103
<input type="button" value="Retour Fiche Objet"/>	
Restauration antérieure	
Restaurateur antérieur: _____ Date de restauration antérieure: _____	<input type="button" value="Retour Fiche Céramique"/>
Nettoyage <input type="checkbox"/> Produits nettoyage: _____	Consolidation <input type="checkbox"/> Produits consolidation: _____
Isolation des cassures antérieures <input type="checkbox"/> Collage <input type="checkbox"/> Produits assemblage: _____	Bouchage <input type="checkbox"/> Produits bouchage: _____
	Retouche <input type="checkbox"/> Produits retouche: _____
<input type="button" value="Fiche Prêt"/>	
<input type="button" value="↕"/>	
Restauration actuelle	
Nettoyage Nettoyage <input type="checkbox"/> Type de résidus: _____ Genre nettoyage: _____ Produits nettoyage: _____	Collage Isolation des cassures <input checked="" type="checkbox"/> Produits isolation: paraloïd B72-acétone 10:90 Collage <input checked="" type="checkbox"/> Assemblage par US <input checked="" type="checkbox"/> Assemblage inter US <input type="checkbox"/> Produits assemblage: Paraloïd B72-acétone 50:50 +aéro:
Consolidation Consolidation <input checked="" type="checkbox"/> Produits consolidation: PB72 10:90 acétone Type d'altération: écaillage	Retouche Retouche <input type="checkbox"/> Produits retouche: _____
Bouchage Bouchage <input type="checkbox"/> Produits bouchage: _____	Mesures de conservation Humidité relative: _____ Température: _____

Fig. 7 – The Ceramics Restoration Form (© MRBC-DMS)

Each material form is linked to a specific Restoration Form describing the cleaning of the object, the gluing, the consolidation and the various conservation measures to be taken.

Depot Management

The organization of the storage room starts with the boxes coming in from the excavation into the transit room. The contents of each box will be inventoried in the Unprocessed Objects Form: the kind of archaeological objects (material), the size of the bags and eventual remarks on the general condition of the objects (fragileness,...).

The objects will then be carefully sorted, separated according to the material, washed, treated, restored if necessary (cf Restoration Form). After having been studied and described in the various object forms and sub-forms by the archaeologist, the objects will be stored in the depot.

Fig. 8 – The Box Form (© MRBC-DMS)

The Box Form and the Bag Form describe respectively the contents of each box and each bag. Each box has a specific and numbered localization in the depot. This localization is at the same time mentioned on the Object Form, facilitating thus the consultation and whereabouts of the object, and in the end the management of the storage room. The various stages of treatment of the bags in each box can be indicated: washed, marked, glued, inventoried. Preformed queries simplify the depot manager's and the archaeologists' questions, e.g. in which box and which bag can be found a certain material/object of a given layer, or, where can one find the various archaeological objects of a certain layer.

A Loan Form contains for each object its date of departure and of return, the institution/location where it went to together with the necessary contact information, the reason (exhibit, analysis, etc.) and insurance information.

Archaeological Research and Depot Management

The entrance menu of the database shows a range of buttons divided in three sections: data-input, research and depot management.

The data-input section gives direct access to the various forms described above. The research section contains buttons activating queries, like e.g. a list of all glass objects from a particular site, the objects found in a certain layer, a list of all stratigraphic layers for one site, etc. New queries can easily be created whenever an archaeologist needs specific information to study the results of an excavation or prepare a publication. The buttons in the management section give immediate access to the Unprocessed Objects

Form, the Box Form and the Bag Form. Several queries result in e.g. lists of all objects moved from the storage room for analysis, exhibition etc. , the localizations of the boxes, the situation concerning the treatment of the objects, etc.

The entrance menu ensures thus easy accessibility for the various persons engaged in data-input.

Future improvement

Future improvement of the database is necessary as the number of entries grows exponentially. It should therefore be developed in a more stable environment, like Oracle or SQL, including the possibility of linking its contents to BRUGis, the GIS site of the Brussels Capital Region that includes all town planning information (<http://www.brugis.irisnet.be/brugis/fr/>). A web-application will give licensed archaeologists in the field immediate access to the database: basic information can then be introduced in a much quicker way. The creation of a virtual museum, retrieving the necessary information from the database, can augment the accessibility of the archaeological archives, be it the excavation documentation or the objects.

Conclusion

The Brussels' Archaeological Heritage Information and Management System presented here has a double advantage for the archaeologist. First, he can conduct and publish the complete scientific study of an excavated site. Secondly, the data-input into one and single database of all the archaeological excavations of one region facilitates transversal analysis. The curator of the depot on his side can track each object placed under his responsibility. With the help of the scientific and technical information gathered during the numerous treatments of the archaeological objects, the depot manager obtains an optimal conservation of the archaeological heritage and guarantees at the same time access for future generations of researchers.

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Automated Processing of Terrestrial Mid-Range Laser Scanner Data for Restoration Documentation at Millimeter Scale

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Abstract: Laser scanning has been shown to be a valuable tool for cultural heritage documentation. Current phase shift scanners produce a huge amount of usually redundant data, which can be hard to handle. Furthermore, with common software packages it is often a time consuming, and thus expensive, process until a satisfactory model of the object is produced. This process typically includes many interactive steps, trial and error and guesswork by the operator. We propose an automated processing chain which takes the raw point clouds from multiple scans as input and outputs a single point cloud, which is much smaller in size, has reduced measurement noise, and a more homogeneous point spacing. Attention is paid at preserving richness in detail as far as possible despite the size reduction. The parameters necessary for the processing are estimated automatically and applied adaptively, taking into account the common properties of panorama scanners and the scan configuration. The result is a point cloud which can easily be handled by common software packages. We tested the method on data from two objects of the *UNESCO World Heritage Site Schönbrunn Palace* in Vienna, Austria.

Keywords: Laser Scanner, Accuracy, Change Detection, Cultural Heritage

Introduction

Terrestrial Laser Scanning (TLS) has proved to be an adequate tool for accurate three-dimensional documentation of cultural heritage objects. The latest generation of phase shift scanners features an extremely high scanning speed and improved accuracy, thus making it possible to capture surface detail in the millimeter range (NOTHEGGER & DORNINGER 2008). This was previously the exclusive domain of close range triangulation scanners (BERNARDINI et al. 2002, BORNAZ et al. 2006). However, due to their restricted field of view, their application for large scale objects is often economically prohibitive. Phase shift scanners, on the other hand, produce huge amounts of data, making high demands on the processing methods used to handle the data. Therefore, the generation of reliable and complete geometric models based on phase shift scanner data tends to be a time consuming, interactive procedure, hence preventing its application for archeological applications.

To reduce the total amount of point data, either the sampling rate during data acquisition may be reduced, or resampling has to be applied afterwards. While the first approach implicitly reduces the richness in detail of the scanned surface during data acquisition, the achievable accuracy of the latter depends on the method used. Phase shift scanners acquire surface points following a regular pattern defined by the instrument's configuration. For performance reasons, many resampling methods rely on this pattern to find neighboring

points for averaging. However, those patterns are related to the instrument and not to the object, where, in general, the point distribution is no longer regular. Especially, varying scanning distances cannot be considered. Therefore, we propose a three-dimensional thinning process which operates in object space, as opposed to image space. Furthermore we propose to choose parameters adaptively based on known location attributes such as the distance from the scanner, incidence angle of the laser beam and angular distance from the zenith. This, additionally, allows for processing point clouds comprising data acquired from different scanning positions, which is of special interest to reduce the effect of inhomogeneous point distributions after merging individual scans and to remove the effects of remaining registration discrepancies.

The technical descriptions of phase shift scanners suggest an achievable accuracy of a few millimeters. However, those specifications do not consider configuration specific parameters influencing the quality of the result. These are, for example, registration discrepancies, inhomogeneous point distribution, varying incidence angles related to the data acquisition setup, etc. Anyhow, the application of adequate post processing of TLS data allows for achieving overall model accuracy of a few millimeter. For this, we propose an automated processing chain comprising thinning and smoothing of the point clouds, registration, and finally, model generation. We demonstrate the achievable accuracy by comparing overlapping scans of an object. To show the application of such high accurate geometric models, we analyze the differences of objects at different scales before and after restoration. Both are part of the *UNESCO World Heritage Site Schönbrunn Palace* in Vienna, Austria. One is a Rocaille stove situated inside the palace and the other is a monumental staircase within the main courtyard. It is shown, that for objects of a few meters extension, millimeter accuracy can be achieved. For objects with an extension of a few dozen meters, the achievable accuracy is better than one centimeter.

Methodology and Related Work

Terrestrial Laser Scanner can be classified according to their measurement principle. The main methodological characteristics are shown in Tab. 1. The highest accuracy may be achieved by triangulation scanner. These scanners, however, usually have a very limited field of view, thus requiring a large number of scans even for relatively small objects. This can be economically prohibitive. For the application of high resolution and highly accurate scanning of large sites, we propose the use of phase shift scanners. Compared to pulse round trip scanners, they have a slightly higher accuracy and, especially due to their extremely high sampling rates of up to 1 million points per second, they allow for subsequently increasing the achievable single point measurement accuracy by adequate post-processing (LICHTI & JAMTSO 2006, NOTHEGGER & DORNINGER, 2009).

<i>Measurement principle</i>	Pulse round trip (Time of flight – TOF)	Phase shift (AM/CW)	Triangulation (Light stripe)
<i>Measurement distance</i>	1 to >2,000 m "long range"	< 1 up to <120 m "medium range"	< 0.1 to 10 m "close range"
<i>Single point accuracy</i>	< ±10 mm	< ±5 mm	< ±1 mm
<i>Sampling rate</i>	up to 150,000 Hz	Up to 1,000,000 Hz	up to 100,000 Hz
<i>Field of view</i>	"panorama"	"panorama"	"window" (< 40 by 40°)

Tab. 1 – Characteristic attributes of terrestrial laser scanner according to their measurement principle.

In general, scanner manufacturers merge precision and accuracy within their technical specifications. While the first is a measure for the repeatability of point measurements – hence, averaging of points allows for minimizing this effect – the influence of the latter (i.e. systematic errors) cannot be overcome easily. A typical example of such systematic errors is a cyclic distance measurement error, well known for electronic distance measurement devices implementing the phase shift measurement principles (e.g. RUEGER, 1990). DORNINGER et al. (2008) describe the detection and proper modelling of such an error for a *Faro LS 880HE* laser scanner. The effect of this error on a triangulation model of a scanned room is shown in Fig. 1 (a & b). Although the magnitude of this effect is less than 3 mm, it has a remarkable negative effect on subsequent analysis processes and it considerably affects the quality of renderings (i.e. virtual models). Fig. 1 (c & d) shows visualizations of the same data after the elimination of the calibration deficiencies.

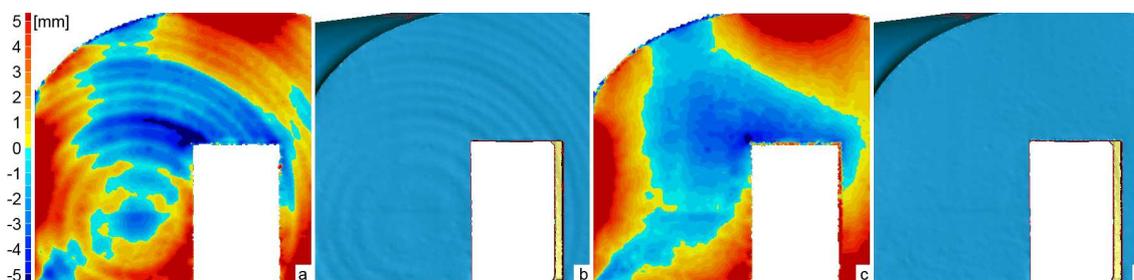


Fig. 1 – Effect of on-the-fly correction of laser scanning data. a & c: normal distances to a regression plane, b & d: rendered model, a & b: original data, c & d corrected data (DORNINGER & NOTHEGGER 2008).

Several processing steps defining a processing chain are required to determine a geometric model from a set of point clouds acquired by a phase shift scanner. The order of the individual steps may differ for different processing chains. Additionally, it is possible to combine steps to be applied simultaneously. We propose a working chain comprising a point cloud processing step to eliminate random errors (noise) from the individual scans, followed by the registration step transforming the scans into a project coordinate system, a subsequent merging of the point clouds, and finally the model generation step (Fig. 2). While the first three steps may be applied automatically without user interaction, for model generation we use a commercial software package (Geomagic Studio) which does not support batch processing. However, due to the pre-

processing of the data, the triangulation functionality of this software can be applied without additional parameter determination.

Data acquisition phase shift laser scanner, up to 1 million points per second, ~3 mm accuracy	
Point cloud processing (3D filtering) scan-wise application, reducing point density and measurement noise, preserving details	automated processing
Registration best fit of overlapping scans (ICP), optional consideration of control- / tie-points	
Merging point clouds (3D filtering) homogenization of point distribution, elimination of discrepancies	
Model generation 3D surface triangulation, optional interactive finalization	

Fig. 2 – Processing chain (blue) for laser scanning based 3D model generation.

The point cloud processing step is applied to the individual scans. It aims at reducing point density and measurement noise considerably while preserving richness in detail as best as possible (NOTHEGGER & DORNINGER 2009). It is designed to be applied automatically in order to cope with the huge amount of data. The number of necessary control parameters is reduced to a minimum and they can be estimated automatically. It is based on the highly robust estimation of surface normal vectors. The normal vectors are used to determine points having the highest probability of being closest to the actual surface (i.e. at the mode of the local point density). The originally acquired points are replaced by the improved ones. As the required control parameters are estimated with respect to the local surface structure, this thinning behaves adaptively. Hence, in areas with more surface detail, more points are kept resulting in an adaptive point density.

For the registration of point clouds (i.e. the transformation of the individual scans into a common project coordinate system), generally two different approaches do exist. For huge scenes, typically tie (i.e. significant, natural object features) or artificial control points (i.e. a priori known tie objects placed within the scene during data acquisition and with an optionally well known position, determined by tachymetric measurements) are used for manual or automated detection of identical points within the individual scans. By least squares adjustment, the discrepancies between those tie features are minimized (ULLRICH et al. 2003). Alternatively, the discrepancies between overlapping scans can be minimized applying an automated point matching approach like the iterative closest point (ICP) algorithm (RUSINKIEWICZ & LEVOY 2001). We suggest using a hybrid approach as described by (AKCA & GRUEN 2007). It allows considering a control point network defined by artificial objects with a priori known positions and, a simultaneous application of the ICP algorithm. This procedure ensures that a predefined absolute accuracy – given by the control points – is achieved while local discrepancies between overlapping scans are minimized as well. Nevertheless, the resulting point cloud suffers from two deficiencies. These are an inhomogeneous point distribution and remaining differences between the individual scans either caused by remaining discrepancies of the registration or by systematic deficiencies not properly eliminated by calibration. To

overcome this, we suggest applying the above described thinning and smoothing method a second time to the merged point cloud, with only a slightly changed set of control parameters.

The result of this processing is an almost homogenous point cloud of the object surface where the effects of measurement noise and registration discrepancies have been minimized. To generate digital surface models from such a point cloud, a three-dimensional surface triangulation is well suited (KAZHDAN et al. 2006). Such models can be used for further analysis of the object. For visual interpretation, renderings using artificial lightning or real textures can be used. Additionally, difference models can be computed for the comparison of different models. For example, the difference of two overlapping scans of an object which were acquired at the same time give an idea of the achievable accuracy of an instrument. By contrast, difference models derived from data acquired of an object at two different times (e.g. before and after restoration) can be used to detect differences at the object for the two different stages. In general, such difference models are computed by assigning all points of model A (e.g. the triangles' corner points) to faces of model B (e.g. the triangles) and computing the normal distance of the points of model A to the faces of model B being closest (in normal direction) to the points. For visual interpretation of such difference models, the distances are typically used as color coded textures mapped to the triangulation models.

Results and Discussion

The documentation of objects and the monitoring of changes are essential for cultural heritage management. Similar tasks are relevant for archaeological sites. For example, artifacts may be moved from one place to another or objects may be reconstructed. Furthermore, continuous movements (e.g. settlements) can be monitored. In the following, we demonstrate the achievable accuracy of triangulation models derived from phase shift scanning data. The datasets were acquired by *Faro* scanners in *Schönbrunn Palace*.

The first testing site is a Rocaille stove of approximately 3 m height. During an extensive restoration, this stove was completely dismantled into pieces with a maximal extension of 30 by 30 cm. For each epoch (before and after the restoration), three scans were acquired (from left, center, and right at equal instrument height) using a *Faro LS 880HE*. The mean sampling distance was 0.7 mm per scan at the object. To demonstrate the relative accuracy of the achievable models per epoch, we analyzed the discrepancies of overlapping scans of epoch 1. The pair wise differences of two scans acquired are shown in Fig. 3 (right). For the majority of the object's surface, the occurring differences are less than 1 mm. Hence, we can assume a model accuracy which is better than ± 1 mm. Fig. 3 (left), shows the differences between the models before and after the restoration. The two models were registered locally (using ICP), as the stove was rebuild at a slightly different position in the room. The detectable differences are up to 35 mm, which is significantly higher than the prior detected model accuracy.

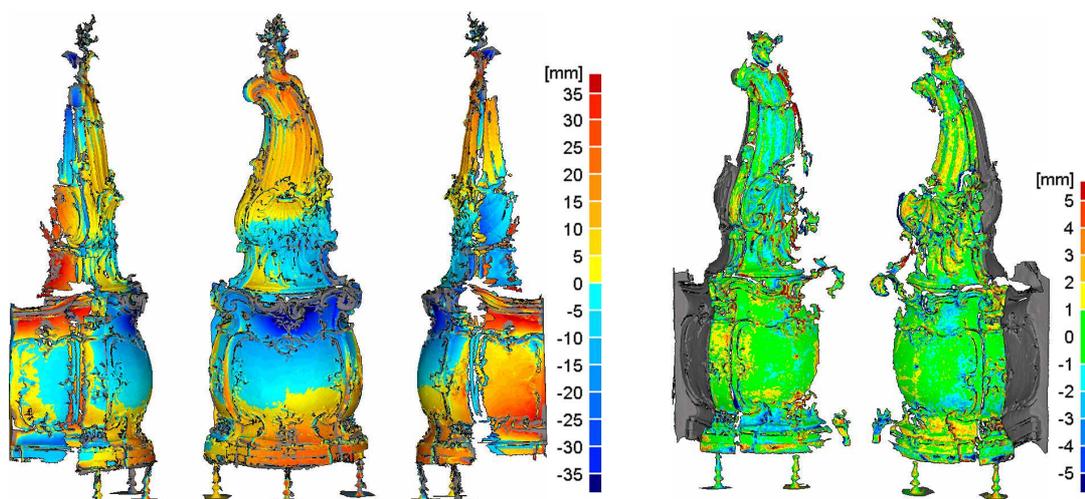


Fig. 3 – Rocaille stove in *Schönbrunn Palace* – Change detection (before vs. after restoration) and accuracy investigation. Maximal differences of ± 35 mm were detected (left) with a relative model accuracy of ± 1 mm (right).

The second testing site is a staircase in the main courtyard of *Schönbrunn Palace*. It has an extension of about 40 by 8 by 8 m. It was scanned by a *Faro LS 880HE* before and by a *Faro Photon* after the restoration. At each epoch, about 40 scans were acquired with a mean point density of 5 mm per scan at the object. Per scan, approximately 15 million points were acquired at the object. Hence, all together more than 600 million points had to be processed. Additionally, a network of tachymetrically measured control points covering the whole scene was determined. To allow for automated detection of these points within the scanning point clouds, spherical and planar targets with an extension of about 10 cm were used. The absolute accuracy of this control point network after network adjustment was about 4 mm. The relative accuracy after the hybrid registration considering the control point network and applying ICP for minimizing discrepancies between overlapping point clouds was about 2 mm. By means of the two filtering steps (confer Fig. 2), the number of points representing the object was reduced to 20 million per epoch, without visible loss of detail. Fig. 4 (top) shows the triangulation model of epoch 2, consisting of approximately 10 million triangles. The color coded difference model (bottom) shows reliably detectable differences between epoch 1 and epoch 2. Differences which are smaller than 10 mm are defined as unchanged and shown in green. The detectable differences have maximum magnitudes of ± 50 mm. They occur in regions where severe constructional problems occurred before the restoration due to improper water draining.

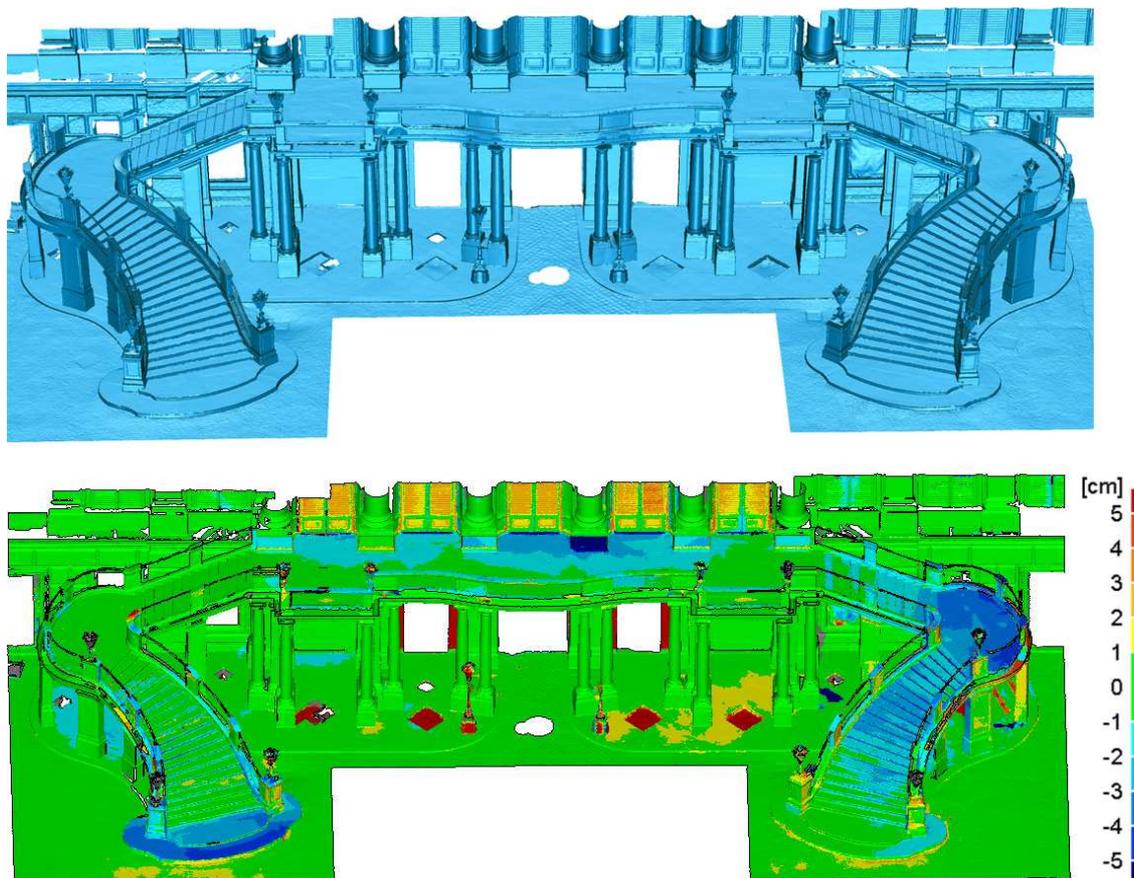


Fig. 4 – Staircase in *Schönbrunn Palace* – Change detection (before vs. after restoration). *Top*: Triangulation model (~10 mio. Triangles) derived from approximately 600 mio points after applying the proposed point cloud processing reducing the number of relevant points by a factor of 30. *Bottom*: Differences before and after the restoration.

Conclusions and Outlook

Common phase shift scanners enable modeling objects with an extension of a few meters at millimeter scale. For larger objects (up to several 10 m), the achievable relative accuracy is about 2 millimeter and by means of a network of tachymetric control points, an absolute accuracy of 5 mm can be achieved. To support this, we proposed an automated processing chain to derive three-dimensional surface models from phase shift laser scanner point clouds. The high degree of automation is achieved by adaptive control parameter estimation. This is an advantage in comparison with most commercial software packages for laser scanner data processing.

To acquire the data of the two testing sites, we defined a scanning setup which did not require scanning distances of more than ten meters. According to our knowledge, for such short distances, the dominant systematic error source are distance measurement errors which can be dealt with properly by means of adequate calibration as demonstrated. For longer ranges, the impact of angular errors increases significantly. The investigation and possible correction of such errors is part of current research.

For scanning and modeling archaeological sites, we expect similar results concerning the achievable quality and richness in detail. However, the maximum object height which may be scanned properly is restricted by

the maximum height of the scanning position. The acquisition of scans necessary to achieve results as demonstrated in this paper takes several minutes. This has to be considered for the selection of the scanning platform as unstable platforms directly reduce the achievable model quality.

Within this contribution, we demonstrated results based on data acquired by phase shift scanners. However, the proposed method may be applied to any kind of three-dimensional point cloud data as no scale dependent assumptions are made. Hence, we expect that this approach has the capability to improve the achievable quality of triangulation models derived from data acquired by alternative measurement systems like close range or airborne laser scanner, or by image matching.

Acknowledgements

We would like to thank the private management of *Schönbrunn Palace* and *Steinmetzbetriebe Bamberger* as members of the *Christian Doppler-Laboratory* for supporting our investigations. Fig. 3 shows a result of the Bachelor Thesis of Dominik Spangl, carried out at the Institute of Photogrammetry and Remote Sensing, TU Vienna.

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Innovative Technology & Ancient History: Exploring Polynomial Texture Mapping (PTM) at Chersonesos, Ukraine

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Abstract: In this paper, I summarize the findings of research in which I assessed the feasibility and sustainability of using Polynomial Texture Map (PTM) technology as a heritage documentation tool at the ancient site Chersonesos located in southern Ukraine. A Polynomial Texture Map is a compilation of multiple digital photographs created with Reflection Transformation Imaging (RTI). Using a mathematical method, a computer program synthesizes the data from the photographs, compiling all of information into one 2D interactive file that, when viewed through PTM viewing software, reveals surface texture and fine detail sometimes not even visible to the naked eye. By photographing larger objects, I hoped to test the feasibility of using PTM as a digital documentation tool within the field of historic preservation. This case study also demonstrates the benefits of the Highlight-RTI (HRTI) capture method. Cumulatively, the case study at Chersonesos and survey of participants indicated that PTM provides a rich source of information about surface detail. Through my research, I was able to establish PTM to be both a feasible and sustainable documentation tool at Chersonesos.

Key Words: Reflectance Transformation Imaging (RTI), Polynomial Texture Mapping (PTM), Documentation, Cultural Heritage, Chersonesos

Introduction

Chersonesos was continuously inhabited for a nearly two thousand year period beginning as early as the fifth century BC until its abrupt destruction in the thirteenth century AD. It is located on the northern coast of the Black Sea and is in the most southwestern region of Ukraine on the Crimean Peninsula. Chersonesos is directly adjacent to the modern city of Sevastopol which is one of the largest cities in Ukraine. The Black Sea connects the site to Mediterranean countries to the west. In addition to the breathtaking views of the Black Sea, there is wealth of existing cultural material from Greek, Roman and Byzantine periods at Chersonesos. Excavations at the site began in the early nineteenth century and continued almost uninterrupted until the present day. As part of my graduate work, I interned at the site for several summers.

I attended a workshop on high-definition technology for heritage management and tourism at the 2007 ICOMOS conference in San Francisco. Carla Schroer and Mark Mudge of Cultural Heritage Imaging (CHI) demonstrated multiple heritage documentation technologies including Polynomial Texture Mapping. They illustrated the many advantages of PTM including the high level of surface detail that can be captured with a portable tool kit. I was curious about the possible applications of the technology at Chersonesos.

In 2007, I conducted a pilot project in which I tested the use of Polynomial Texture Mapping (PTM) at Chersonesos in Ukraine. My research was completed in collaboration with the Institute of Classical

Archaeology at The University of Texas at Austin (ICA) and the National Preserve of Tauric Chersonesos.¹⁴⁹ Cultural Heritage Imaging (CHI) provided me with assistance and guidance throughout the documentation process.¹⁵⁰

Polynomial Texture Mapping (PTM): The Technology and How It Works

Reflection Transformation Imaging (RTI) is a term used to “describe an image-based method to acquire the reflectance properties of an objects’ surface” (Corsini 2006, 1) originally coined by Tom Malzbender and Dan Gelb of the HP Laboratories. Polynomial Texture Mapping (PTM) is one way in which RTI information can be mathematically processed. A PTM is a compilation of multiple digital photographs in which everything but the light source remains stationary. Using a mathematical method, processing software synthesizes data from the photographs, and locates the highlight position in each shot, compiling surface reflectance information into one 2D interactive file. When examined with specialized viewing software, surface texture and fine detail sometimes not even visible to the naked eye is revealed.

PTM can be used to document different size objects on very different size budgets. With a larger budget, a prefabricated frame can be manufactured to provide the light source. One advantage to using a pre-fabricated frame is that location of each light position has been already been established. This system of acquisition automates the lighting process and eliminates supplemental calculations during processing. There are several disadvantages of using this approach, however. For example, fabricating the frame can be quite expensive and transporting such a frame can also be quite cumbersome. Furthermore, the framing device dictates the size of object that can be photographed.

At Chersonesos, I chose the Highlight RTI (H-RTI) method, also referred to as the ‘Egyptian method’. During the capture sequence, highly specular black balls are photographed in each shot. Processing software then calculates the position of the highlights in the black balls in order to determine the light position. Benefits of using this capture method are that it can be carried out on a relatively small budget with an easily transported tool kit on objects that can range from “two square centimeters to multiple square meters.” (Zanyi 2007, 22.4) The H-RTI tool kit includes a digital SLR (single-lens reflex) camera with remote control ability and accessories, tripod, light source and reflective black ball(s).¹⁵¹

¹⁴⁹ The Institute of Classical Archaeology at the University of Texas at Austin (ICA) has been conducting research collaboratively with National Preserve of Tauric Chersonesos (NPTC) at the site since early 1990s with generous funding from Packard Humanities Institute (PHI).

¹⁵⁰ Cultural Heritage Imaging (CHI) is a non-profit company that supports the development of innovative technologies as a way to digitally share and preserve cultural heritage around the world. In the summer following my original research, CHI held a workshop at the site in which they trained Ukrainian students and staff how to use the technology.

¹⁵¹ At this time, only one black ball is used during the processing sequence. However, it is my understanding that software is being developed in which the use of two black balls may aid in the extraction of 3D information. It is also good practice to photograph two balls in case the highlight detection software has trouble locating one of the balls.

During the documentation process, the light source is moved around the surface of the object while the object, camera and black balls remain completely stationary. Because the processing software compresses reflectance information per pixel, it is important first to set the object on a completely stable surface. (See Fig. 1: C) This includes taking into consideration the flooring.¹⁵² The black balls are then positioned next to the object far enough away from it that they can later be cropped out of the shot during processing.

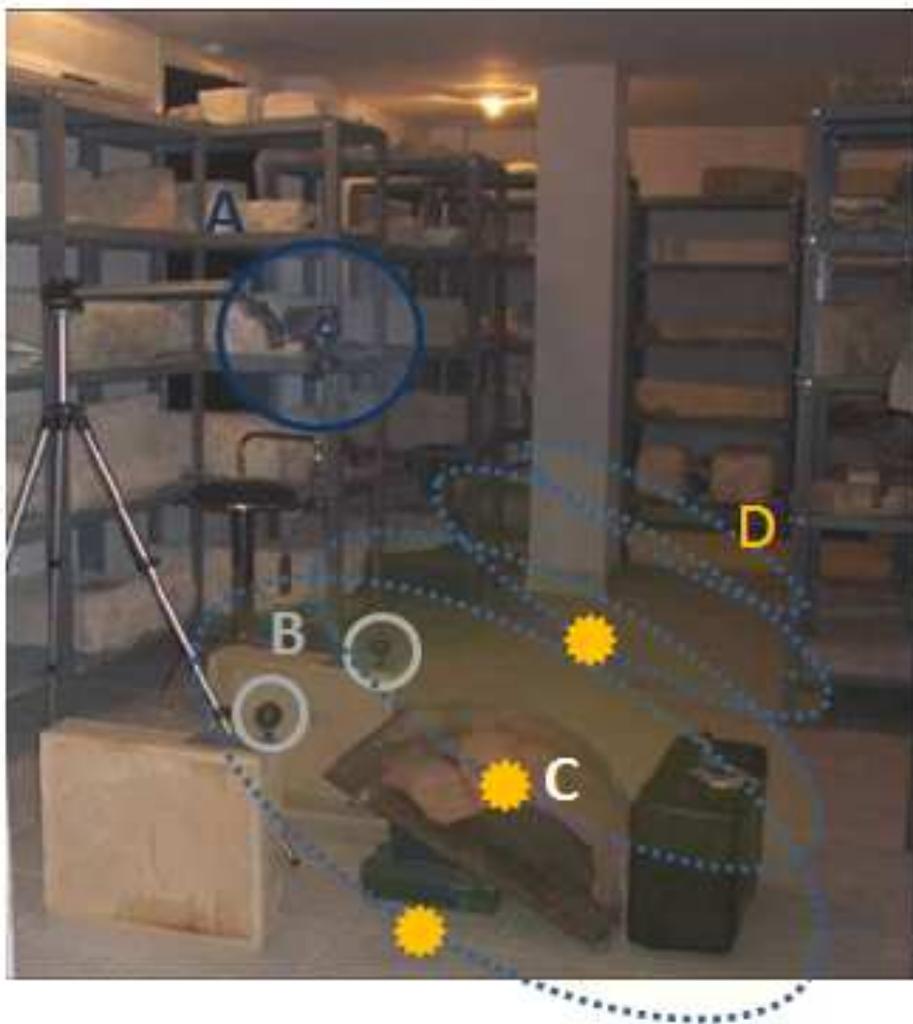


Fig. 1 – Documentation set-up at Chersonesos (Copyright: Sarah Duffy)

(Fig. 1: B) The camera is mounted on a tripod with the object and balls in view and set to capture in RAW format. (Fig. 1: A) Once the camera is in position and in focus, it is set to manual. For the remainder of the photo sequence, the camera should not be touched, and is operated by remote release. The light source which can be either flash or continuous is separated from the object at a distance three to four times the object's diameter. In each of the multiple shots, the light is moved to different positions around the surface of the object creating a virtual dome. (Fig. 1: D) A grey card should be photographed during the capture sequence for calibration during the processing phase. Unless specialized filters are used, ambient light should be minimized or eliminated completely during the photo sequence.

¹⁵² Even wood flooring can throw the pixels off in a photo sequence.

A PTM can be generated from as little as 16 photographs. One of the first steps in processing a PTM is converting the photographs, originally captured in RAW format, into DNG (Digital Negative) format. During this step, color is calibrated using the grey card and other bundle adjustments to the exposure parameters and orientation are made. Next, JPEGs are generated from the DNGs and then run through software that locates the highlight center in the black ball for each shot. The light position coordinates (x, y, z) are reported in a .txt file. A second set of JPEGs are generated from the DNGs in which everything but the object is cropped out of the shot. Those JPEGs and the light position .txt file are fed through software specially developed by Hewlett Packard in order to create a Polynomial Texture Map. Finally, the PTM can be viewed with the appropriate viewing software.¹⁵³

PTM Technology offers many advantages to the field of historic preservation. For example, it is an excellent tool to use in order to gather information about surface detail, PTMs are easily shared via the internet and objects in remote sites can be documented using a transportable tool kit. Additionally, in terms of budget, PTM is a comparatively inexpensive documentation option since it can be carried out using a relatively inexpensive tool kit and requires a time commitment of approximately an hour per photo sequence including processing.¹⁵⁴ Some of the disadvantages of PTM include possible operator error, lack of quantitative data and limitation of subject size. Additionally, though much of the processing is completed using open-source software, proprietary software is required in order to generate a PTM.

PTM at Chersonesos, Ukraine: The Case Study

During the summer of 2007, I piloted a PTM project at Chersonesos with the intention to test the feasibility and sustainability of using the technology at the ancient site. Furthermore, I wished to test the feasibility of using PTM within the field of historic preservation in order to record architectural elements. Because Chersonesos is relatively remote, my budget was small and I wanted to record larger objects, I chose the H-RTI capture method.

To test the feasibility of using PTM at Chersonesos, I documented several artifacts. In particular, I chose to photograph larger objects in order to test the feasibility of using the technology for architectural documentation. Finally, in order to test the sustainability of using the technology at Chersonesos, I conducted a survey on the PTM methodology. I included Ukrainian college students, specialists and Chersonesos staff members and ask specifically questions about their impressions and opinions of using PTM technology at Chersonesos. The surveys were formatted on a 5 point Likert scale with: 1 = strongly disagree, 2 = disagree, 3 = undecided/neutral, 4 = agree and 5 = strongly agree. In each set of surveys, there was also a short comment section included.

The learning curve for the exercise, while not insurmountable, was labor-intensive and often frustrating. The logistical problems proved to be the most time-consuming. Logistics included finding an appropriate space that was large enough and stable enough to document, gaining permission and access to the objects long enough to finish the documentation session, procuring compatible equipment, and finding available power

¹⁵³ Note that there is a new processing workflow available but it was not available at the time of this research.

¹⁵⁴ The H-RTI tool kit consisting of a digital camera, tripod, light source and black balls can cost well under \$1000.

sources for the lighting equipment. The cultural differences and language barriers also created problems during the process.

However, the advantages of using PTM technology far outweighed the challenges. I successfully captured photographs of larger artifacts during my research at Chersonesos that, with assistance from CHI, were generated into a PTM. The largest object I documented was the top surface of an abacus from an Early Byzantine stone column which measured approximately 58 cm x 85.5 cm. The piece was repurposed into bench, and was later used as a game board. The incisions from those ancient games are still faintly visible today. Due to copyright limitations, I cannot include images of the artifacts documented during my case study. However, to illustrate the power of PTMs in capturing surface detail, I have included a few screen shots of a PTM that I have since produced at a rock art site in United Kingdom. (Fig. 2)



Fig. 2 – Left: Digital photograph

Middle: Screen Shot PTM viewed with specular enhancement tool

Right: Normal map

While I did use a Likert scale in my surveys, it was not my plan to do statistical analyses. The survey sample at the site was simply not large enough to allow for quantitative statistical analysis. Instead, I used the numerical scale as an easy way to gather qualitative data among Ukrainian, Russian and English speakers. With primarily numerical scores, I could quickly process the survey results without needing to heavily rely on a translator. The purpose of the survey was to use the data to triangulate my research, using my own participant experience, the experiences of the college students who assisted in the documentation phase and finally the experiences of the specialists, staff members and students who had hands-on experience using the web-based PTMs.

Before I started the survey, I directed participants to a web-based PTM and allowed them to interact with the technology first. When asked 1) if PTM was an interesting/engaging tool and 2) if they were interested to use the technology in the future after their experience with PTM, the twenty respondents indicated their high level of agreement with an average score well over 4 (on a 5 point scale). Responses to the open-ended comment section of the survey were that PTM was “a very good idea” and “very exciting”. It left one of student participant “wanting more”. Staff members were curious about how it could be used as an educational tool for students outside of Sevastopol and its possible application with glass objects. However, respondents did voice concerns about publication issues (e.g. people having access to unpublished artifacts on the internet) and whether or not the strength of the light source could damage fragile polychrome objects. The specialists

commented that PTM was “marvelous” and pointed out possible applications within the study of epigraphy and numismatic collections.

Conclusions

Cumulatively, the case study at Chersonesos and survey results from those who would be using the PTMs indicated that PTM provides a rich source of information about surface detail than other documentation technologies. Not only was I able to successfully capture the photographic data necessary to create a Polynomial Texture Map at the site, but I received positive feedback that such technology would be well received at the site in the user surveys I conducted with staff, students and specialists. Furthermore, by documenting larger objects, I illustrated that PTM technology could potentially prove to be a useful documentation tool in the field of historic preservation for recording architectural elements. Additionally, this case study demonstrates the benefits of the Highlight-RTI (HRTI) capture method: that it can be carried out on a small budget with an easily transported tool kit thus allowing heritage documentation at remote sites such as Chersonesos.

In summary, the case study supports the position that Polynomial Texture Mapping is a powerful tool to use in order to gather information about surface detail. A series of digital photographs are synthesized into one interactive file which can be used to study surface detail, often revealing more information than even the naked eye can detect. In short, the 2D interactive file provides information about 3D surfaces that other documentation methods cannot provide. While PTM technology may not be the most appropriate tool for every project, this case study indicates that it has advantages over many traditional and innovative technological documentation methods. First, PTMs can be created using a very inexpensive, transportable tool kit. Additionally, because the viewing software is free and the information can be easily presented on the web, PTMs can be shared world-wide, fostering international research collaborations with professionals who may not be able to travel to remote sites. Finally, the use of PTM technology ultimately protects the object to be documented; by creating an interactive tool that can be reviewed unlimited times, the danger of damaging the object due to repeated handling is mitigated.

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Application of non-destructive acoustic techniques for evaluating the state of conservation of carbonate building stones in architectural structures

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Abstract: This experimental work focuses on the application of non-destructive acoustic techniques to evaluate the conservation state of carbonate stones commonly employed as building materials in the architectural structures of the Mediterranean cities. In this work the acoustic ultrasonic techniques were used to define quantitatively the conservation state of building materials and better understand their alteration processes. Measurements of compressional and shear wave velocities have been carried out in laboratory and the relationships between the above mentioned geophysical measurements and meaningful physical properties of rocks as uniaxial compressive strength and Young modulus have been carefully evaluated to correlate these parameters with the elastic ones. On the basis of these analyses *in situ* ultrasonic investigations were carried out on significant monuments of the historical downtown of Cagliari (Italy) to acquire objective information on the conservation state of the building materials and evaluate the effectiveness of the repair actions to damaged zones inside the structural elements. The results of this study have highlighted that the application of acoustic techniques in conjunction with the laboratory measurements of rock properties (petro physical study) may contribute effectively in defining and quantifying the alteration phenomena of the building materials of monuments also allowing to monitor their health status.

Keywords: non-destructive testing, acoustic techniques, architectural structures, carbonate rocks

Introduction

In recent years the study of the propagation of acoustic waves through a stone material is becoming of increasing importance to determine its dynamic properties hence its mechanical behaviour. With regards to this fact the non-destructive acoustic techniques can be considered an efficacious tool in the characterization of the rock materials in several sectors of applied research (Casula *et al* 2009; Christaras 1997; Fais *et al* 1999; 2005; 2008; Galan *et al* 1991).

In this study the acoustic measurements in the ultrasonic range 24-82 kHz have been performed in laboratory on several specimens of three different carbonate rock types (limestone) also studied from petrological point of view to correlate their petro physical features with the elastic ones. Prismatic unaltered specimens (12x12x24 cm) were prepared for the application of the ultrasonic techniques according to C.N.R. - I C R - Normal 22/86 and also for the study of rock properties of the materials. Furthermore a number of representative thin sections was prepared to study the materials under optical microscopy and analyze the textures and the arrangement of voids.

On the basis of the results of the laboratory measurements, *in situ* applications on significant monumental structures in order to check zones of weakness, to assess the alterability of the investigated stones and evaluate the restoration effectiveness have been also carried out.

Rock properties

In this study the laboratory tests have been performed on several specimens of the three different carbonate rock types (limestone) dated to Tortonian-Messinian periods (Cherchi & Pecorini 1969; Leone *et al* 1992).

These rocks are named from top to bottom *Pietra Forte*, *Tramezzario* and *Pietra Cantone*.

As is known in the carbonate lithologies, rock properties (as texture, porosity, mineralogical composition) depend on depositional environment and diagenetic mechanisms that convert a freshly deposited carbonate sediment into an indurated rock (Anselmetti & Eberli 1999; Eberli *et al* 2003). The diagenetic processes generate complex physico-chemical phenomena as dissolution and fusing of grains by cementation. These processes often change the original framework in terms of mineralogical composition and textures including the rearrangement in pore shape and size. All these phenomena change the rigidity and stiffness of a carbonate rock and consequently its elastic properties and its mechanical behaviour. Therefore considering all these aspects also to improve the knowledge of the study carbonate stones providing the best criteria for understanding their alteration processes a petrological study was performed. A number of representative unaltered samples was studied by optical microscopy in order to obtain information on the physical arrangement of their constituent grains.

At microscopic observations *Pietra Cantone* (Fig. 1a) shows the typical characteristics of muds-supported carbonate rocks, from mudstone to wackestone (Dunham 1962) made up of foraminifera and calcareous skeletal remains as bivalves and gasteropoda. These grains are supported by a matrix of microcrystalline calcite mud. It has been also observed a terrigenous component mainly made up of quartz, feldspar and biotite. Furthermore all samples show variable amounts of iron oxides and hydroxide specks. Optically visible porosity (macro-pores) was counted by the petrographic analysis of thin sections (Cantrell & Hagerty 1999). The rock has a secondary porosity of vug and mouldic types (7.0 %).

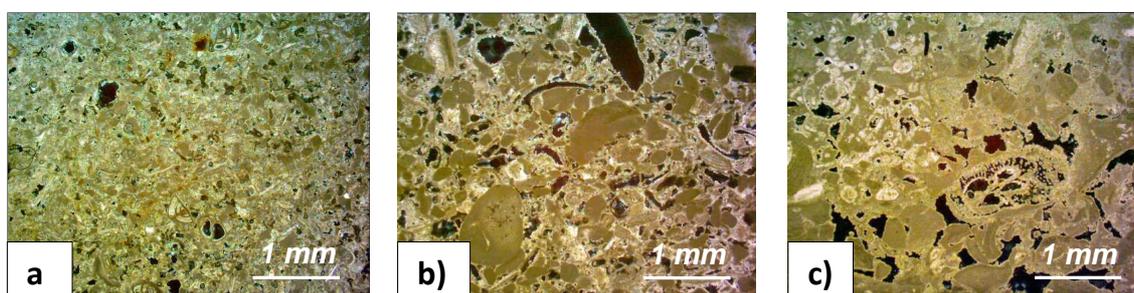


Fig. 1 – Photomicrographs of the study carbonate rocks on representative thin sections under cross-nicols. (a) *Pietra Cantone*, (b) *Tramezzario*, (c) *Pietra Forte*

Tramezzario can be ascribed to a grainstone (Dunham 1962). The petrographic thin section examination shows a grain-supported typical texture with a pore-filling cement of sparry calcite. The rock has a various bioclastic content made up of skeletal grains of bivalves, *Lithothamnium* algae, gasteropoda and echinidae.

Tramezzario is generally characterized by mouldic porosity (9.0 %), the internal casts of pores show the presence of sparry calcite. *Pietra Forte* shows the textures of a typical limestone of reef environment in which the original components were bound together by organisms as abundant Lithothamnium algae and minor mollusks. This texture can be ascribed to a boundstone (Dunham 1962). The porosity type of this rock is similar to that of *Tramezzario* (1.2 %).

The carbonate content of the study materials was determined by calcimetry (Tab. 1). *Pietra Cantone* has carbonate contents lower than those of the other two lithotypes due to the presence of a terrigenous component. Other rock properties as apparent and real densities were calculated according to BS EN 1936:2006 (Tab.1).

ROCK PROPERTIES	<i>Pietra Cantone</i>	<i>Tramezzario</i>	<i>Pietra Forte</i>
<i>Dunham classification</i>	Mudstone/Wackestone	Grainstone	Boundstone
<i>CaCO₃ content (%)</i>	84	91	91
<i>Apparent density (Kg/m³)</i>	2228	2400	2620
<i>Real density (Kg/m³)</i>	2690	2700	2720

Tab. 1 – Mean values of rock properties of the study carbonate rocks

Laboratory acoustic measurements

Prismatic unaltered specimens (12x12x24 cm) sampled in the main outcrops and ancient quarry sites of Cagliari were prepared for the laboratory acoustic tests. Portable Ultrasonic Non-Destructive Digital Indicating Tester (PUNDIT) device by C.N.S. Electronics LTD was employed for the tests in the ultrasonic range 24-82 kHz. A number of experimental sessions was carried out choosing different modalities of acquisition techniques. Particularly the indirect (transmitter and receiver on the same face of the investigated sample), semi-direct (transmitter and receiver on the adjacent faces of the sample) and direct transmissions (transmitter and receiver on the opposite faces of the sample) were carried out. For the experimentation the silicone snug sheets were chosen as coupling agent because they were evaluated as better coupling agent with respect to vaseline (Concu & Fais 2003).

Measurements of compressional and shear wave velocities (ISRM 1981a) have been carried out and the relationships between some physical properties of the investigated rocks and the above mentioned acoustic measurements have been carefully evaluated. Acoustic methods are very effective in detecting the elastic characteristics of stone materials even though data interpretation is very complex as elastic wave velocity heavily depends on moisture, heterogeneity, porosity and other physical properties (Casula *et al* 2009). The propagation of elastic waves through the rock samples allows to assess the dynamic properties of rocks and consequently their mechanical behaviour. Uniaxial compressional strength was calculated on six prismatic samples following the procedure outlined by ISRM (1979, 1981 b). The P and S-wave velocities in the 24-82 kHz ultrasonic range were calculated on the basis of the measurements performed on six samples of each carbonate rocks already considered for the uniaxial compressional strength determination (Tab. 2).

LITHOTYPE	Vp (m/s)	Vs (m/s)	Uniaxial compressional strength (kg m ⁻²)
<i>Pietra Cantone</i>	2700	1400	4.0 x 10 ⁴ ÷ 8.50 x 10 ⁴
<i>Tramezzarlo</i>	4700	2500	20 x 10 ⁴ ÷ 200 x 10 ⁴
<i>Pietra Forte</i>	6500	3300	200 x 10 ⁴ ÷ 700 x 10 ⁴

Tab. 2 – Mean values of the ultrasonic longitudinal and transversal pulse velocities and uniaxial compressional strength on the investigated carbonate rocks

Moreover in Fig. 2 is shown the relationship between the dynamic modulus of elasticity (Young's modulus - Ed) and the compressional wave velocity (Vp) of a number of representative samples of the study rocks. The analysis of the graph highlights that *Pietra Cantone* has the lower values of Ed with an exception of a sample (Ed of about 45 GPa). This fact can be related with the textural features of this sample in particular the degree of cementation of grains that is higher with respect to that normally observed for *Pietra Cantone* and similar to that of *Tramezzario* lithotype. The *Tramezzario* sample with Ed value of about 15 GPa presents textural characteristics (as porosity, type and degree of cementation) similar to that of *Pietra Cantone*. This fact puts in evidence the complex behaviour of these rocks which in a few cases can not be easily and strictly classified because they have to be considered as passage facies.

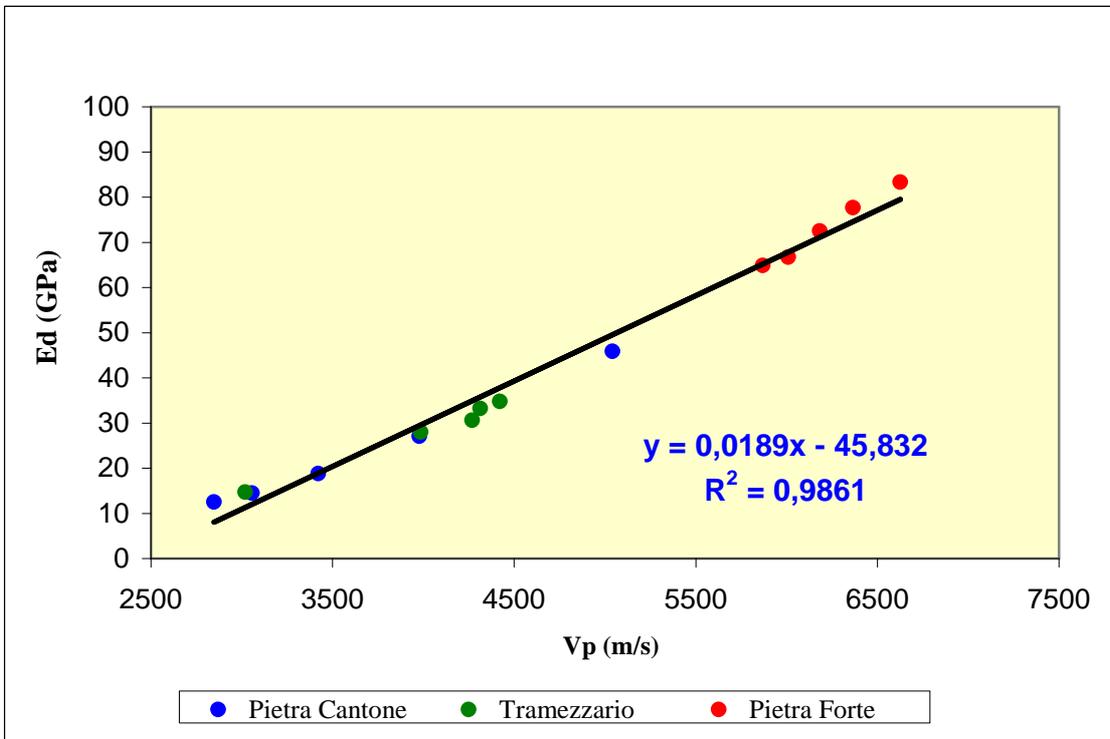


Fig. 2 – Longitudinal wave velocity (Vp) vs Young modulus

Considering the petrological aspects previously described and the velocity values measured on the rock specimens, it can be deduced a strong influence of the petrology on the elastic wave propagation. Shape

and size of the grains, pore size and geometry, clay content, density, degree and type of cementation among others were considered in relation to the observed velocity variations, however as already recognized from other Authors (Wang 2000) it is not possible to define the effect of each parameter without considering the effects from all.

***In situ* acoustic measurements**

On the basis of the results of the laboratory measurements, an *in situ* ultrasonic survey was carried out by the indirect method (Fig. 3a) using the equipment shown in Fig. 3b. The *in situ* applications have been aimed to draw up ultrasonic compressional wave velocity maps on the investigated structural elements in order to check zones of weakness, to assess the weather ability of the carbonate stones and evaluate the effectiveness of the restoration works. In fact, alterations in the material cause a decrease in the ultrasonic velocity, which can be used as representative of its elastic properties. In this paper are reported as example two cases study from the historical city centre of Cagliari.

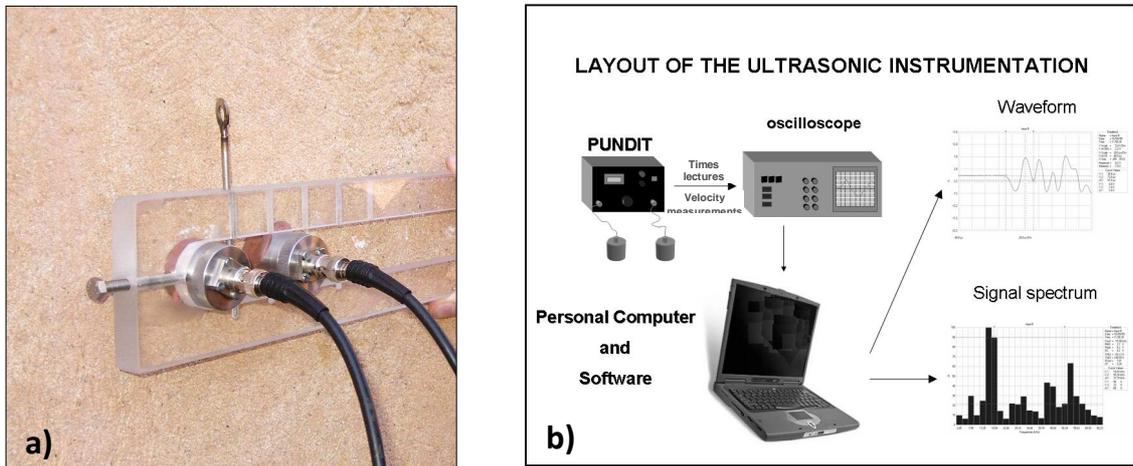


Fig. 3 – *In situ* ultrasonic survey: data acquisition phase by the indirect method (a); ultrasonic equipment (b)

Case study 1: Fig. 4 shows the ultrasonic longitudinal velocity maps obtained by interpolating the velocity values measured by the indirect method along profiles carried out on three columns of the indoor colonnade of the San Lorenzo Church.

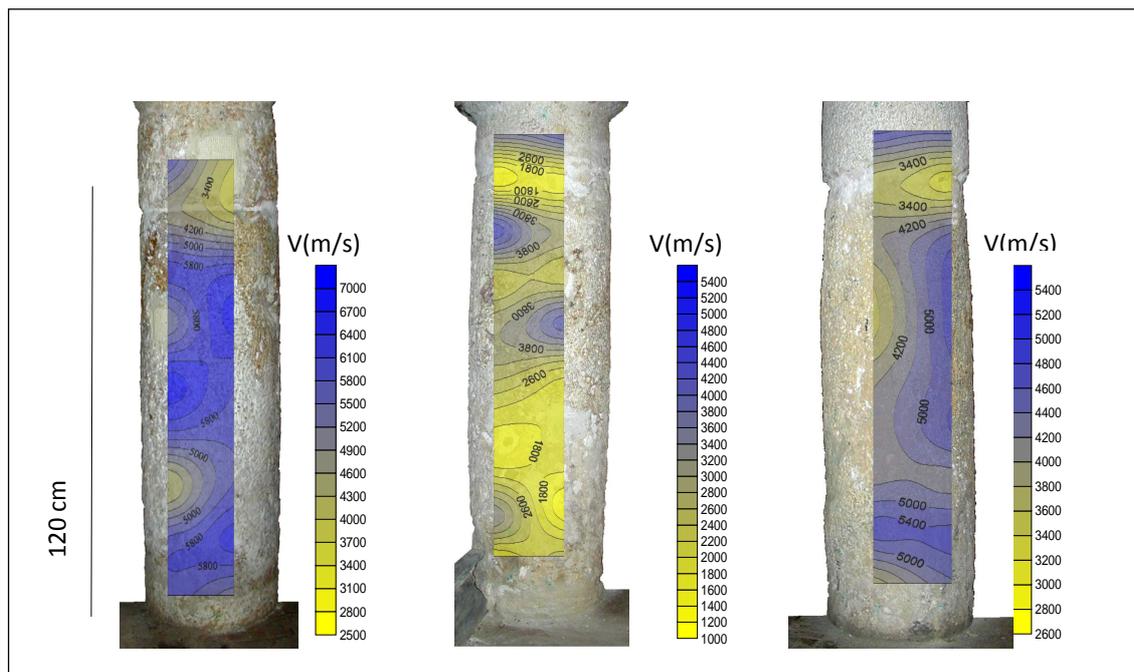


Fig. 4 – Ultrasonic longitudinal velocity maps obtained by the indirect *step by step* technique at 54 kHz

As deduced from different tests carried out in various conditions, the velocity values must be interpreted as relative. Recognised this fact, the velocity map indicates variations of the elastic status of the material and then of its integrity. The low velocity areas in the maps represent mainly degradation of the building stones and weakness zones, as can be also deduced both comparing the in situ longitudinal velocity measurements with the laboratory results and considering the information deduced from the petrological study.

Case study 2: Fig. 5 shows the application of acoustic tomography technique in a masonry wall of Palazzo Regio historical building (Fais et al 2002). Fig. 5a exhibits the critical sector of the investigated masonry structure on the lower part of the monumental structure selected for this application. Fig. 5b and c display respectively the data acquisition scheme (b) and the cross-correlogram (c). This latter was obtained by computing the cross-correlogram functions (Fais et al 1999; Fais & Casula 2010) between representative data sets of the transit time from different combination source-receivers. The interpretation of the cross-correlogram was used as constrain for the input velocity model of the tomographic reconstruction (Fig. 5d) of the investigated section, through the masonry walls. The tomographic velocity reconstruction (Fig. 5d) displays a low velocity zone (marked in red colour) that can be correlated with a zone characterized by low mechanical resistance that persists up to a depth of 40 cm in the wall. Two micro cores were located in the higher (3500-4000 m/s) and in the lower (2000-15000 m/s) velocity zones in the wall and the mineralogical analyses of the collected samples fully corroborated the results obtained by the acoustic tomography.

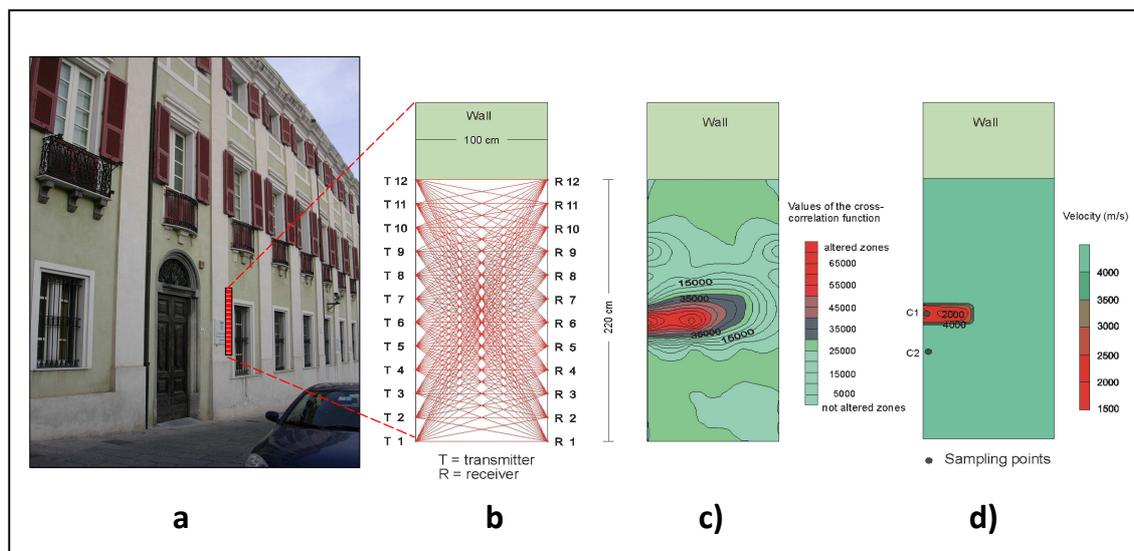


Fig. 5 – Palazzo Regio: location of the acoustic tomography (a); data acquisition scheme (b); cross-correlogram (c); tomography velocity reconstruction (d)

Conclusions

The integrated analysis of laboratory and *in situ* ultrasonic measurements performed on three carbonate rock types (limestone) used as building stones in monumental structures of the historical centre of Cagliari (Sardinia) was effective in assessing the dynamic properties of these rocks hence their mechanical behaviour.

Many features of the investigated carbonate rocks influence the propagation of the elastic wave, therefore to correctly interpret the ultrasonic behaviour of the materials a study on rock petrology was also carried out. From our integrated study results that the longitudinal ultrasonic velocity increases with decreasing porosity and increasing carbonate content and density (*Tramezzario* and *Pietra Forte*). Many other petrological factors influence the ultrasonic velocity in a more complicated way and it is not possible to define the effect of each parameter without considering the effects from all.

From laboratory and *in situ* measurements it results that a strong reduction in the propagation velocity of the ultrasonic signals is connected to the presence of inhomogeneities as micro cracks or micro fractures and pores. The use of the elastic waves in the ultrasonic range (24-82 kHz) through the materials integrated with information on petrology of the rocks has been successful to assess the rock quality and better understanding their alteration processes. In the matter of the fact the application of the above mentioned technique can be also considered relatively cheap. In the case study 1 the cost of the investigation was at about € 200,00 per map considering an acquisition time of one and a half hour per map, processing and interpretation included. Thus the integrated approach used in this study may represent a cost-efficient tool to define and quantify the degradation phenomena of monuments and in monitoring their health status. Moreover, starting from the acoustic measurement results it is possible to reduce the need of sampling materials (micro cores) also making stone conservation actions more cost-efficient.

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An Open Way for Archaeological Data Management Based on Quantum GIS

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Abstract: The Geographical Information System has great potential for handling and analysing spatial data. Archaeological information – features and finds - are also spatially distributed.

This paper focuses on the creation of a comprehensive spatial database for the documentation of archaeological excavations and the use of this system for further analyses. The main aim of this work is not only to combine all archaeological features and finds, but also to understand the spatial distribution of these objects. We used GIS - Open Source Software (Quantum GIS) as the main platform of this project. Archaeological excavations of medieval settlements in Ingelheim (Germany) were carried out between 1994 and 2006. Pits, pit-houses and various stone constructions were found during these excavations. We used different information sources such as: old and modern cadastral maps of Ingelheim and topographical maps (in a 1:5000 scale), excavation reports, field drawings and images for the creation of the database.

The first part of the poster will present the process of database preparation. Also, the way in which various elements of the archaeological documentation were digitised and brought together into one system will be explained. In addition, we will demonstrate an approach to the integration of geographical and archaeological information.

The spatial analysis of archaeological features and related finds will be delineated as preliminary results. Subsequently, we will depict the generating process of the historical digital elevation model (DEM) for this settlement.

A further purpose of the project is to investigate the wider context for this find spot and the integration of results and information from the whole settlement cluster in Ingelheim.

Keywords: GIS, Open Source, Data Management, Spatial Analysis, DEM

Introduction

Archaeological excavations of medieval settlements in Ingelheim (Germany) were carried out between 1994 and 2006. The research took place in the “village” part of medieval Ingelheim, 500 m away from another significant monument, i. e. the Palatium, built in the 8th century by the Carolingians. This colony fulfilled the role of economic support for the Palace. It was situated close to St. Remigius/St. Kilian Church, whose early medieval existence has been confirmed by written sources (BÖHNER, 1964: 51, 56; GREWE, 1998: 34; GREWE, 2007: 104).

The excavations were executed in three phases and within five zones (O1 – O5). The first excavation was realised in the course of building the “Ottonenstraße” in four campaigns between 1994 and 1998. Further

research took place a few years later, i. e. in 2001, 2005 and 2006. The study area is shown on the overall plan (Fig. 1).

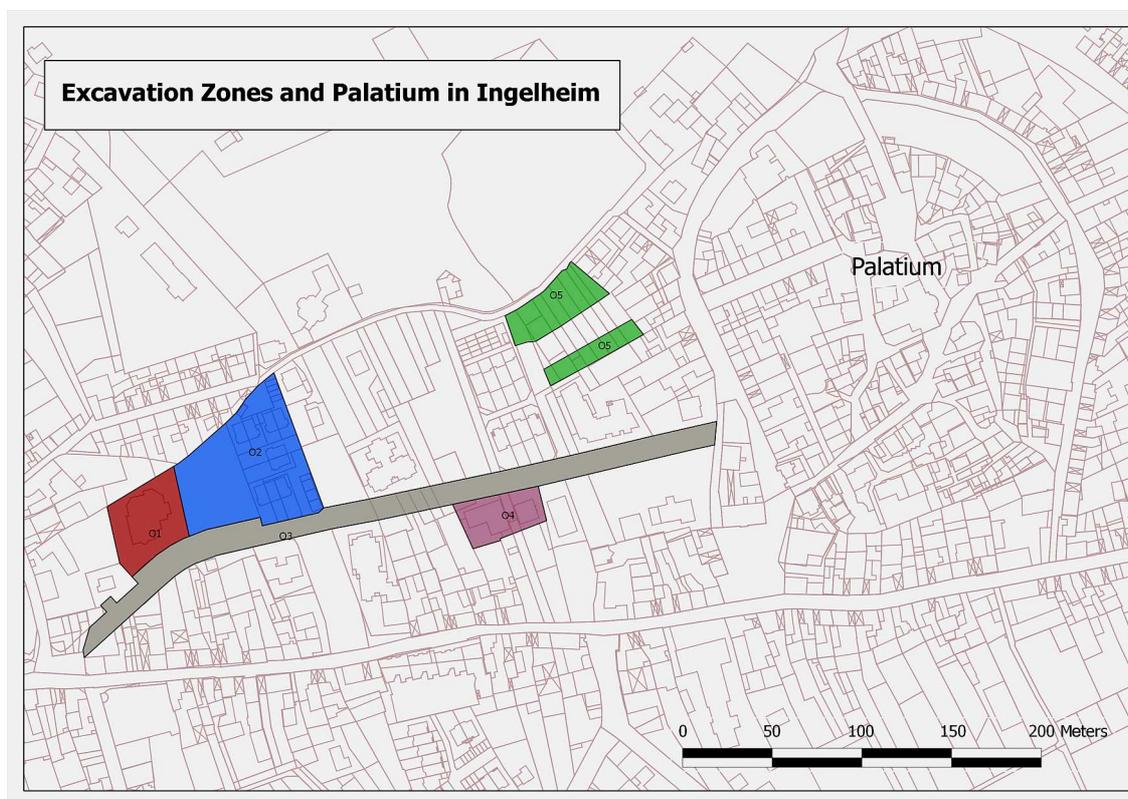


Fig. 1 – Excavation zones and Palatium in Ingelheim (Copyright: Forschungsstelle Kaiserpfalz Ingelheim)

This paper focuses on one part of this excavation, namely research carried out in 1996 within the O-2 zone. The largest area, with about 19 sections, was explored during this excavation stage. The famous and unique gold solidus, probably minted during the reign of Charlemagne, was also found at that time. Among other remains of pits, pit-houses and related postholes were also found there. Archaeologists discovered various stone constructions, e. g. different masonries and stone settings, which covered a large area. This settlement dates from the Early to the High Middle Ages. Ceramic analysis and precise dating are still in progress.

Goals

The main goal of the project is to use an open source GIS-based application to integrate all information from the archaeological excavation, i. e. archaeological features and finds, and to localise them on the map with a determined spatial projection.

Subsequently, the major aim of this research is to understand the spatial distribution of archaeological data from the medieval settlement in Ingelheim and to execute a number of spatial analyses on this data.

Our objective was also to convert all analogue drawings, images or reports into digital form, and to store them in a specific database designed for this project. With this study we intended to get an intense view on the data of this particular find spot.

In addition to the preliminary data analysis, a new method for processing the excavation results and management of the archaeological information will be presented.

Input data

As input data we used archaeological field documentation.

During the excavation almost all the field drawings were made in a 1:20 scale. Apart from that, a field lay-out plan of the whole research area with selected archaeological sections was created.

Field reports were written on the excavation site using standardised field sheets for the description of archaeological objects, structures and features.

Field photos were taken only with an analogue camera. A scale and north arrow are visible on each photograph, but these are not photogrammetric images.

A cadastral map of the city of Ingelheim and a topographic map in a 1: 5000 (TK5) scale were used for the precise localisation of archaeological sites.

All data sources had previously been available only in analogue form and had to be digitised manually.

Archaeological field drawings and some of the photos were scanned and converted into JPEG raster data.

The database was completed with other information taken from the field reports.

Methodology

The spatial data related to the archaeological excavation was stored and managed using open source software *Quantum GIS (QGIS)* in *Version 1.3.0 "Mimas"*. QGIS is an application with many common GIS-features and functions that supports vector, raster and database formats.

To display data correctly, it was essential to specify the coordinate system. In Quantum GIS we used the *Coordinate Reference System (CRS)* dialogue box to set it. Owing to the location of our project area and the specific coordinate system of the used sources, we chose the German Main Triangular Network (DHDN) 3-degree Gauss-Krueger zone 3; EPSG: 31467.

Georeferencing is the process of assigning known coordinates to some points of raster data, in this case the local coordinates and marks point from the scanned field drawings. For this operation we used the Quantum GIS georeferencing raster plugin *Georeferencer*.

The field drawings were scanned as JPEG with a resolution of 300dpi. Firstly, the field lay-out plan was georeferenced with the coordinates (Gauss-Krueger, zone 3) from the cadastral plan of this area. The further step was to georeference almost all field drawings for each archaeological section. The corners of each area were marked in the georeferencer, as well as in the main display with the lay-out plan with all trenches.

The choice of transformation depends on the type, quality and the degree of geometric distortion of the input data. Polynomial equations are among the most widely used for georeferencing. First-order polynomial transformation (orthogonal transformation) allows scaling, translation and rotation, which are applied equally across the whole map or image. To georeference the field drawings we used this transformation with three or four control points. "The number of control points to use is dependent on how radical the rectification needs to be: simple orthogonal transformation needs only two or three points, but a badly distorted aerial photograph or satellite image requires many control points to compute an accurate warp" (CONOLLY, 2006:

86 – 88). The resampling method we chose was the nearest neighbour in order to make no changes in the image statistics (Quantum GIS, 2009: 154-155).

In this case the accuracy of the cadastral map conditions the accuracy of all single rasters.

At the same time, we developed a database particularly for this unique find spot. The relational database we created contains 19 various archaeological components, e.g. zone, dating, ceramic-finds and bone-finds. It allows for an analysis of all kinds of collected information, both spatial distribution of archaeological artefacts and features on-site. Only selected finds with a known location were saved as separate files. At a medieval excavation, the finds are usually assigned to the archaeological features or parts of them, they do not receive an exact location. The additional information about the features and finds is based on the description, reports and catalogue.

The first database was created in *Quantum GIS (QGIS)* in *Version 1.2.0 "Core"*. It was then replaced by the "Mimas" version, which has some new features, especially in the editing toolbar. Another very important advantage of this new version is the possibility of extending the *shapefile* of other attributes.

Vectorisation (*digitising toolbar – toggle editing*) is the process of converting raster data to vector features. Vector data is stored as a collection of geometric objects, such as lines, points and polygons. In the Quantum GIS we used simple heads up digitising by applying the Capture Point/Line/Polygon tool from the editing toolbar. A raster image is used as a backdrop layer. The scans of the archaeological field drawings, the cadastral map of the city of Ingelheim and the topographic map were applied in this project. The digitising and editing process consists of drawing the geometry in the map view and then entering its attributes. This is repeated for each archaeological feature.

Firstly, a new vector layer (*shapefile*) of the known geometry (point, polyline or polygon) and appropriated attributes are created. The archaeological features were digitised as polygons and the height values as points. Moreover, the zones and trenches were digitised as polygons in separate *shapefiles*.

Secondly, we edited fields in the attribute table (relational database with 19 various archaeological components). For the attributes we chose some common components, where we entered the attribute values for the feature that describes the archaeological data-phenomena. Attributes can be stored as: integers (whole numbers), floating points (decimal numbers), strings (words) or dates. After we had completed the digitising process our data was saved as a commonly used file format shapefile, which is actually a group of three files (.shp, .dbf and .shx). Additionally, information about the coordinate system and spatial projection was stored as a .prj file.

Finally, all of the created *shapefiles* were saved as one *.qgs project file* and presented as various maps. After the editing, a few further analyses were made on the point heights. Some of them were chosen to generate the historical digital elevation model (DEM). It was not possible to obtain the height values for one excavation layer from the whole area. The points were compared in both directions: in the direction of the natural inclination and perpendicularly to the slope. This collation helped us to remove the elevation values that were not related to the historical utility layer. From the appropriate values a new raster (DEM) was interpolated with the non-statistical method – Inverse Distance Weighting (IDW). A cross section with the inclination and the elevation of the terrain was also made for a better understanding of the historical topography. (Fig. 2)

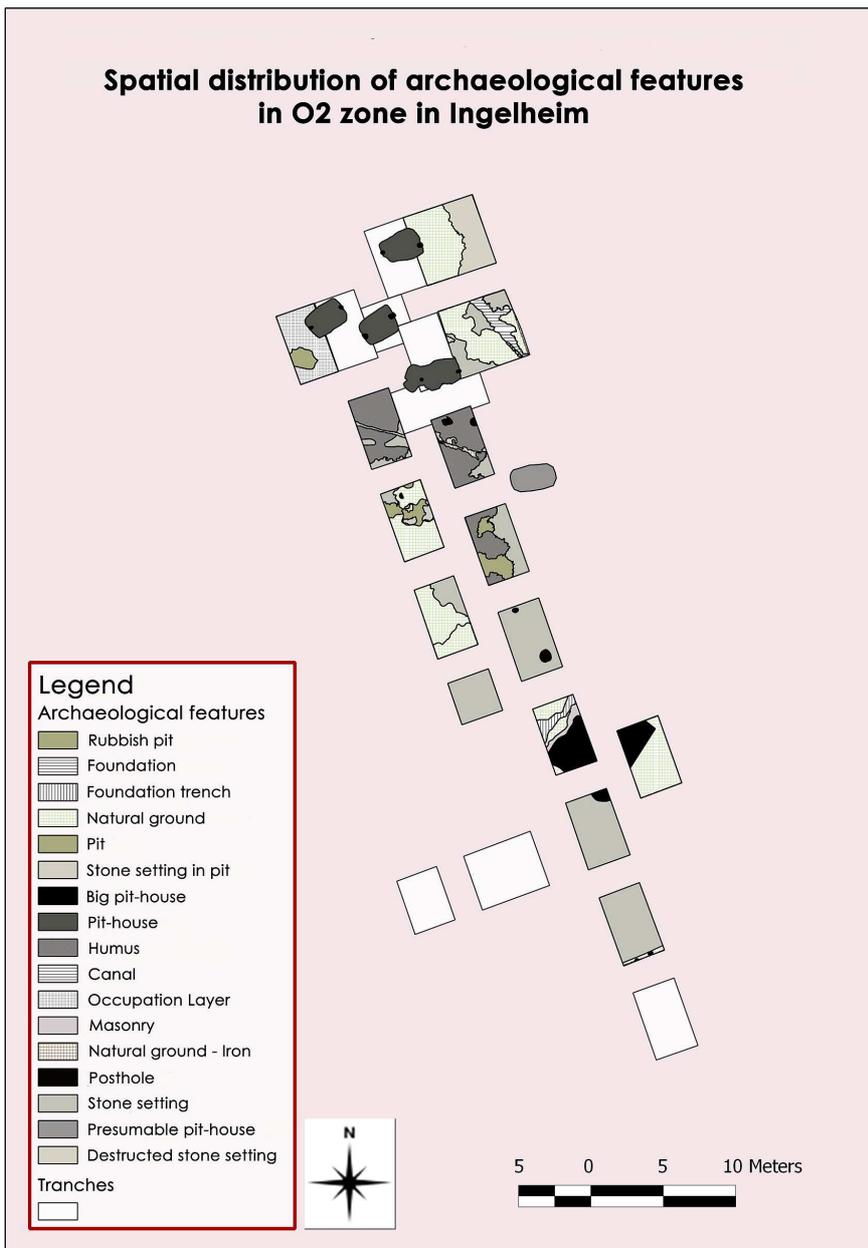


Fig. 3 – Spatial distribution of archaeological features in O2 zone in Ingelheim (Copyright: Forschungsstelle Kaiserpfalz Ingelheim)

Figure 4 shows the spatial distribution of each archaeological object and its dating. The oldest features are of early medieval origin, the youngest are modern.

The next three maps present the spatial distribution of the archaeological finds. We chose ceramics and bones as a group of numerous artefacts. The finds appear in the database as attributes of each archaeological feature. Apart from the finds, which are presented on the maps, there are also other artefacts, e. g. slates, spindle whorls or combs, in the database.

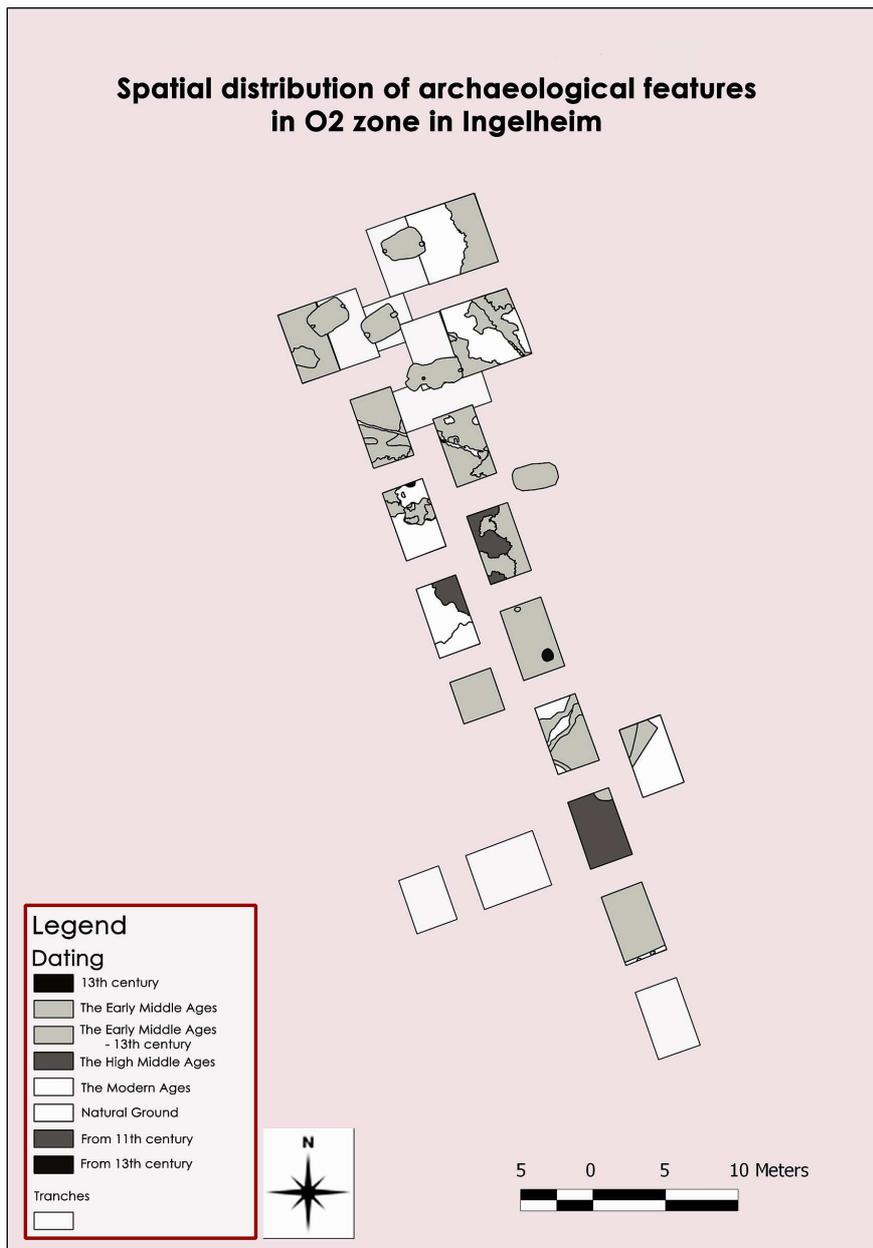


Fig. 4 – Spatial distribution of archaeological features in O2 zone in Ingelheim - Dating (Copyright: Forschungsstelle Kaiserpfalz Ingelheim)

We can distinguish three sectors in the settlement. The northern part is characterised by a large number of pit-houses and postholes associated with them. The four encountered archaeological objects are of similar size, about 2.00 x 3.00 m, and an approximate depth of 0.2-0.3 m.

Due south, a few other pits were excavated in the centre of the investigation area. These objects differ from the pit-houses in the northern part. They have much smaller dimensions and a different form. No traces of postholes were found close to them. These features could not be distinctly interpreted. Presumably they had a rubbish or storage function.

There were some stone constructions and settings found in the middle and in the eastern part of the excavation area. This could be interpreted as a “square” or some kind of central place with a number of pits and postholes. This archaeological feature has a diverse structure and composition in different parts of the

research area, from a relatively thick layer of about 0.5 m to single stones placed directly on the natural ground. Between the stones remnants of mortar, clay and sand were found. The postholes could sustain a roof construction or they are the remains of a fence between the parcels/plots.

Another building, a large pit-house, was found in the southern periphery of the excavation field. The discovered remains of this domicile/structure had the dimensions of approximately 5.00 x 6.00 m and a

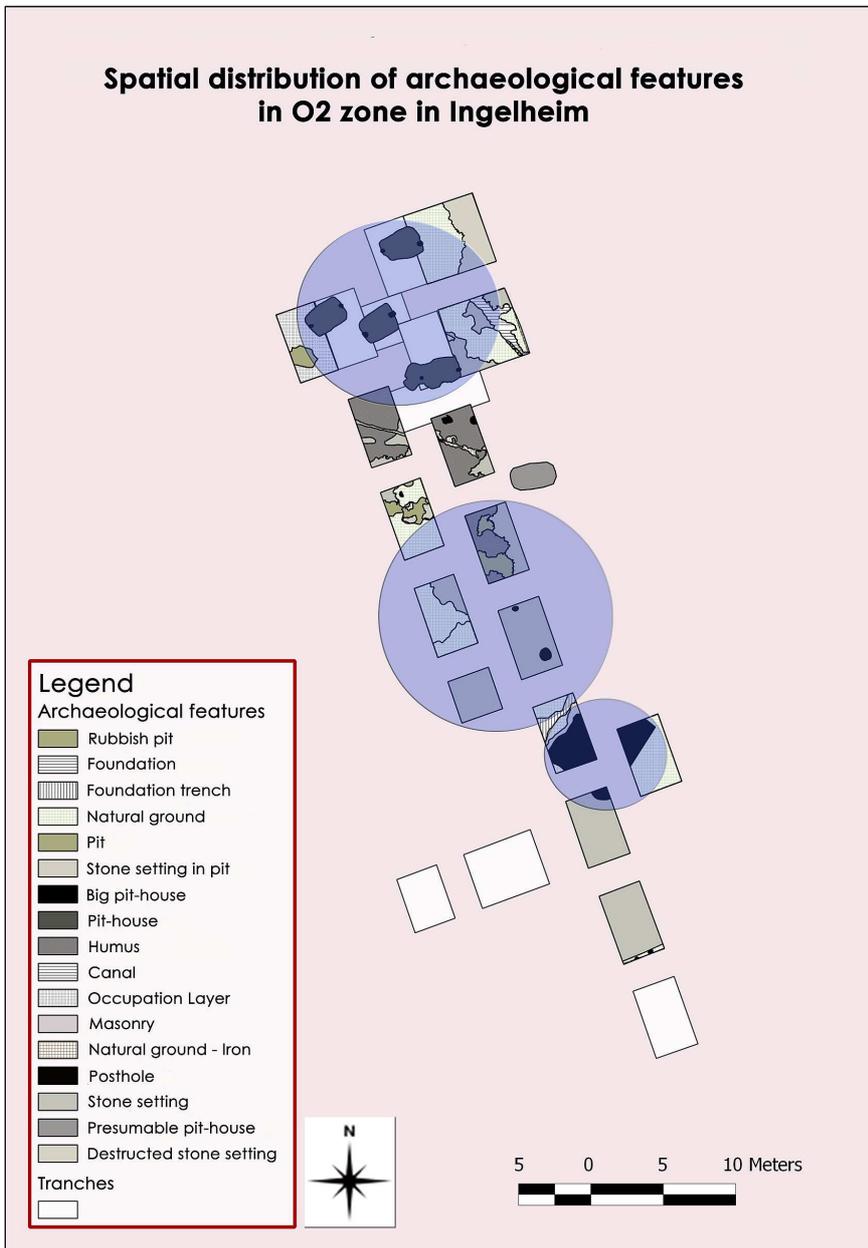


Fig. 5 – Spatial distribution of settlement sectors in O2 zone in Ingelheim (Copyright: Forschungsstelle Kaiserpfalz Ingelheim)

A backfill of this object indicates two phases of use: the first is related to the building and to the first use of the feature. After that, the lower part was filled with a different material. In this period a masonry structure was built along the north wall. Made from limestones, lime and mortar it probably sustained the whole construction. In the southwestern part of this zone no further archaeological features were discovered. This could be explained in a twofold manner, namely either this part of the settlement was not included into the medieval “village“ or the preservation conditions were not very supportive.

After the preliminary dating of the finds, almost all of the pit-houses and pits are dated as early and high medieval settlements. The precise dating of the features and the finds will be evaluated in the forthcoming part of the research.

There is also some regularity in the spatial distribution of the archaeological finds in the whole research area. Most of the archaeological finds are distributed in the pit-houses and some of them in the middle zone. The ceramics and bones were found in the pit-houses, which were situated in the northeastern part of the “village”. (Fig. 6, 7). Apart from that, whorls, bone combs and various metal objects were discovered. Their function could not be specified due to poor preservation status.

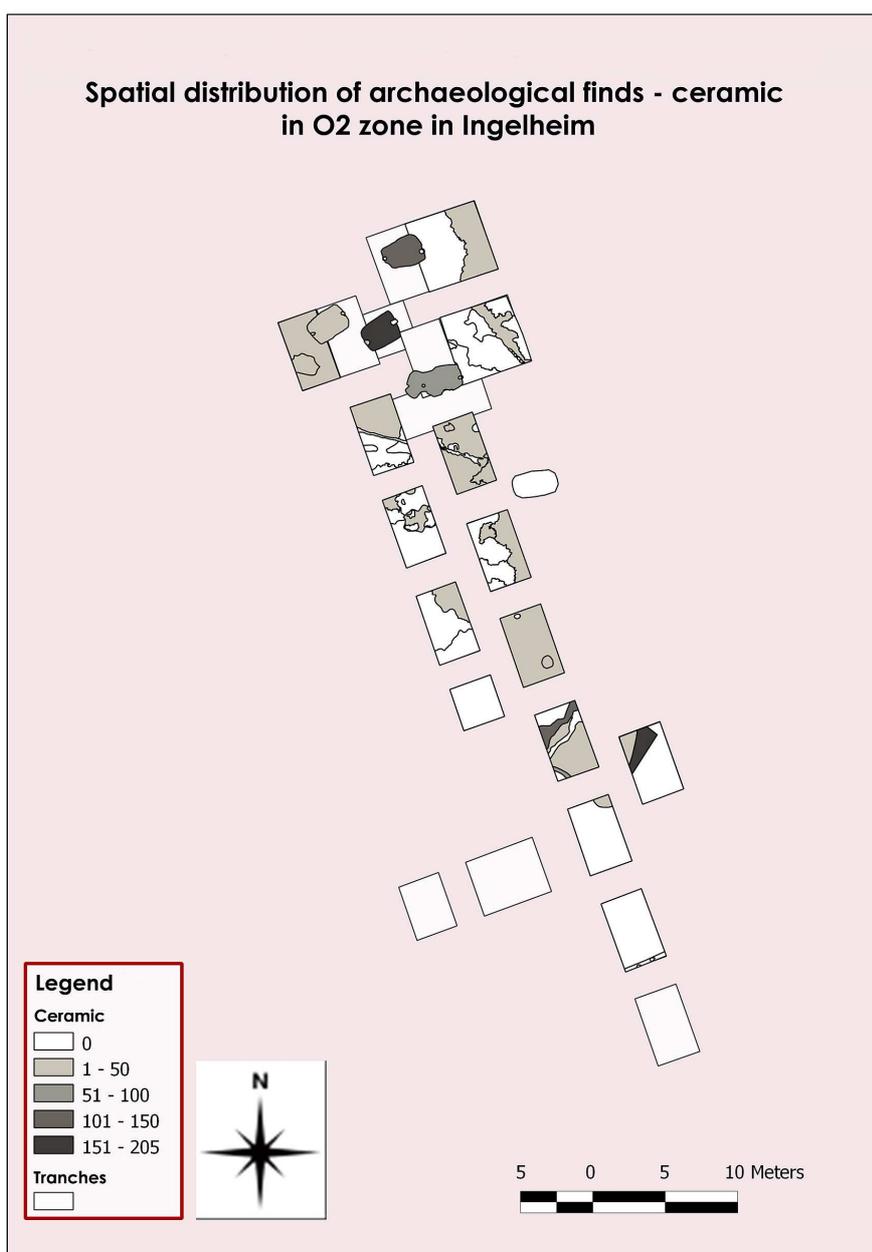


Fig. 6 – Spatial distribution of archaeological finds - ceramic in O2 zone in Ingelheim (Copyright: Forschungsstelle Kaiserpfalz Ingelheim)

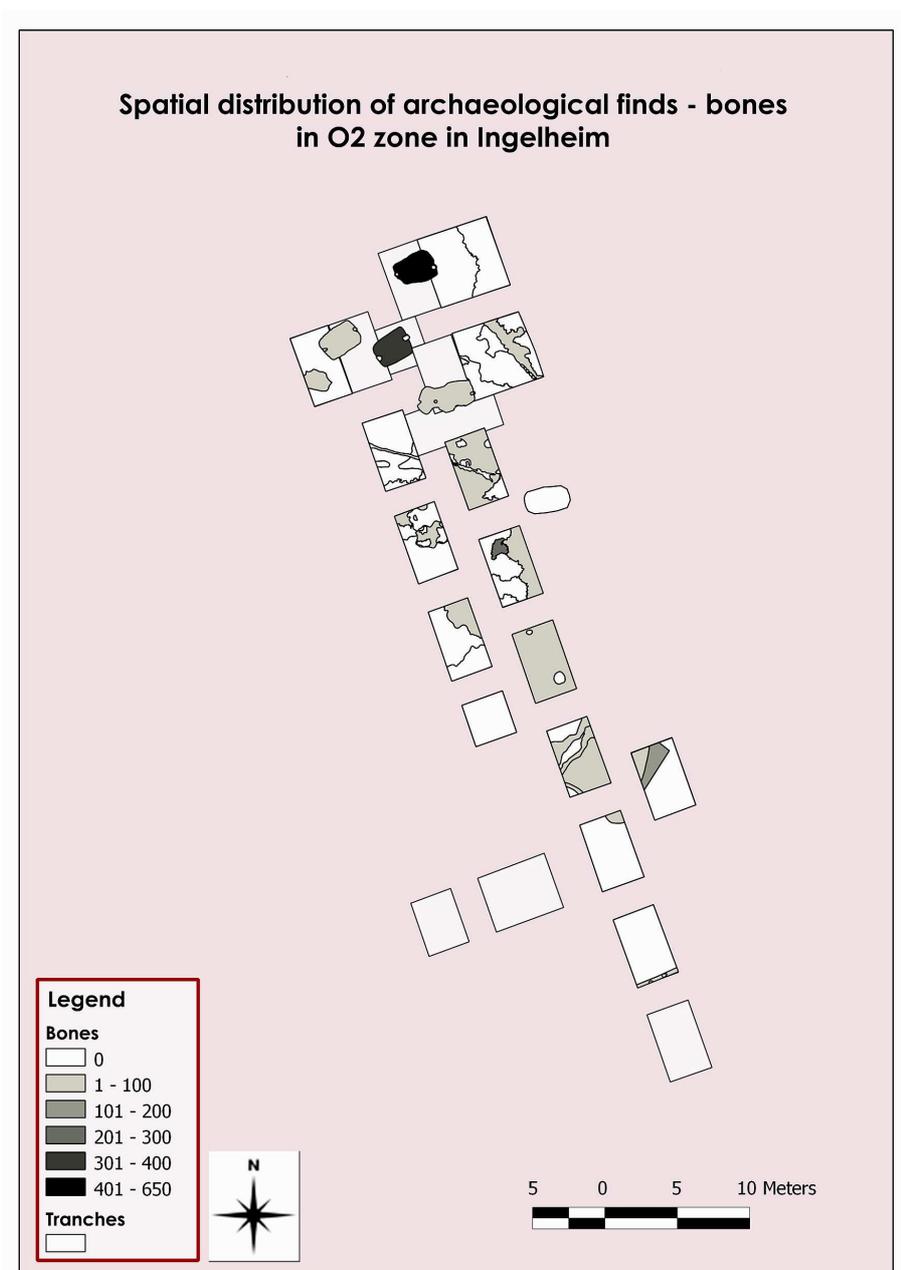


Fig. 7 – Spatial distribution of archaeological finds - bones in O2 zone in Ingelheim (Copyright: Forschungsstelle Kaiserpfalz)

In the above-mentioned pit-house, situated in the southern part of this area, a large number of slag and shale fragments occur. The famous solidus of Charlemagne was also discovered in this object (Fig. 8). This coin was in the primary fill of this archaeological feature (GREWE, 1998: 35; MARTIN, 1998: 37, 38). Subsequently, a few further analyses were made on the height points. Some of them were chosen to generate the historical digital elevation model (DEM) of this zone. In further research the height values from other zones will be evaluated to generate a historical digital elevation model for the whole area. The modern terrain will also be surveyed and its model interpolated. These two rasters will be evaluated and compared. Finally, the terrain changes between the Middle Ages and the present will be investigated with map algebra and a comparison of the cross sections.



Fig. 8 – Gold solidus found in O2 zone in a big pit-house (Copyright: Forschungsstelle Kaiserpfalz Ingelheim)

Conclusions

Quantum GIS is a relatively effortless and useful open source software which helps to organise and manage data. It supports the understanding of both the spatial distribution of archaeological features and finds. For an initial evaluation and comprehension of the archaeological data it is easy to understand and to apply, but it is not suitable for extensive spatial analyses.

We have presented only the first phase of the research in the medieval settlement in Ingelheim. In the next stage of this evaluation we would like to include all of the other zones from this area in the database and expand the spatial analyses with the application of another GIS-programme, namely the GRASS GIS.

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Extraction of archaeological features from high-resolution LIDAR data

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Abstract: In May 2009, the State Office for Cultural Heritage Management Baden-Württemberg launched a three-year project aimed at the complete archaeological mapping of Baden-Württemberg using high-resolution airborne LIDAR (Light Detection And Ranging) data, covering an area of 35751 km². The goal is the verification and extension of the existing archaeological data base. To achieve this goal, a data processing method and workflow for the extraction of Local Relief Models from LIDAR-based Digital Elevation Models was developed. Colour-coded maps of these Local Relief Models are found to be a valuable tool for archaeological prospection. First results of the project confirm the feasibility of using LIDAR-based data for the archaeological mapping of very large areas.

Keywords: LIDAR, laserscan, archaeological mapping, feature extraction

Introduction

The federal state Baden-Württemberg in south-western Germany is rich in archaeological heritage from the Palaeolithic onwards. Numerous Neolithic, Bronze and Iron Age, Roman, Merovingian, medieval and early modern sites make Baden-Württemberg a region of great archaeological importance (cf. LAD, 2009, for an overview of recent archaeological research in Baden-Württemberg). Of particular importance are sites dating to the early Celtic period like the early Iron Age hill fort Heuneburg, which is argued to be the earliest urban settlement north of the Alps. Of comparable importance is the Upper German and Rhætian segment of the Roman Limes which is part of the UNESCO World Heritage system.

However, it is unknown to what extent the current state of knowledge approximates the actual number of sites. This is particularly relevant given the high forest cover of 39% of the state which renders large areas as blank spaces for archaeological prospection by aerial photography. Residential and industrial sprawl, construction of roads, railway lines and pipelines, mechanised agriculture and forestry practices as well as looting pose serious threats to known and unknown archaeological sites. Before this backdrop of the urgent necessity for spatially extensive archaeological prospection, LIDAR (Light Detection And Ranging) data are being developed as a valuable archaeological tool.

This paper presents the methods and first results of an ongoing project aimed at the complete archaeological mapping of Baden-Württemberg based on high-resolution LIDAR data.

LIDAR remote sensing

In recent years, high-resolution Digital Elevation Models (DEM) based on airborne LIDAR (Light Detection And Ranging, also known as Airborne Laser Scanning, ALS) have emerged as a new data source for the prospection, mapping and monitoring of archaeological sites.

LIDAR is an active remote sensing technique in which the land surface is scanned by a high-frequency pulsed laser beam from an airborne platform (usually airplane or helicopter). This laser beam is backscattered by the ground surface or by the vegetation canopy, and the distance between transmitter and the backscattering object is determined from the time of flight of the laser signal. Together with the GPS-derived position, the INS-derived roll, pitch and yaw of the platform as well as the deflection angle of the transmitted laser beam, this allows the creation of high-resolution digital models of the landscape (Wehr and Lohr, 1999). One of the main advantages of LIDAR is that by filtering the backscattered signal and using only the last backscattered pulse of the laser beam, the true land surface – even under vegetation canopy – can be detected. This allows the generation of high-resolution Digital Elevation Models (DEM) (Crow et al., 2007; Devereux et al., 2005; Doneus et al., 2008; Sittler, 2004).

Local Relief Models (LRM)

LIDAR-based DEM are becoming increasingly available on a regional to national scale, and their recognition as valuable data for archaeological purposes is growing. However, most archaeological applications of LIDAR have until now been limited to the visual interpretation of shaded relief representations of the DEM at different simulated illumination angles (elevation and azimuth) (e.g. Harmon et al., 2006; Bofinger et al., 2006; Boos et al., 2008; Risbøl et al., 2006; Romain and Burks, 2008a, 2008b, 2008c). In this case, the visibility of potential archaeological features depends to a large degree on the chosen illumination angles, making their detection unreliable or time-consuming (e.g. Devereux et al., 2005).

As archaeologically relevant structures are usually characterised by very low relief relative to the elevation range of the surrounding landscape, they often appear as comparatively subtle features. One goal of LIDAR data processing for archaeological prospection can therefore be seen in the problem of having to extract local small-scale, low-relief features from the DEM and eliminate as far as possible the large-scale landscape forms from the data. Several data processing steps (Figure 1) have to be applied to extract small-scale (detail) topographic features for archaeological interpretation:

1. A DEM is produced from the vegetation-filtered LIDAR point cloud data (in the present case with a pixel size of 1 x 1 m).
2. A low pass filter is applied to the DEM. This smoothed elevation model represents a first approximation of the large-scale landscape forms. The kernel size of the low pass filter determines the spatial scale of features which will be captured in the LRM. In the present case, a kernel size of 25 metres is used for the low pass filter. This size was found experimentally to result in a good representation of many previously known archaeological features and is therefore assumed to work well for the detection of

previously unknown features. Features much larger in diameter or cross-section are uncommon; furthermore, they would be conspicuous in conventional shaded relief images of the DEM. Degraded representation for much smaller features than the kernel size may become a serious issue if they are underlain by strongly convex or concave terrain (e.g. hilltops or ridges, valley bottoms), but is less pronounced on smooth slopes.

3. By subtracting this smoothed elevation model from the DEM, a first approximation of the local relief is achieved: only small-scale topographic features are preserved in the model while the large-scale landscape forms are eliminated. However, because small-scale features are smoothed rather than eliminated by the low pass filter, the model derived by this approach is biased towards small features, i.e. the local relief elevations are progressively underestimated as spatial extent of the features increases.
4. A purged DEM is created from the DEM point elevations along the zero-metre contour lines in the LRM. This purged DEM represents the large-scale landscape forms after cutting out rather than smoothing small-scale features.
5. Subtraction of this purged DEM from the original DEM results in the final LRM which reflects less biased elevation information of small-scale features relative to the landscape at large.

In comparison to using a simple difference map between the DEM and its low pass or median filtered derivative (Doneus and Briese, 2006; Hiller and Smith, 2008), the LRM derived using this approach results in a less biased representation of small-scale topographic features which reflects more truthfully the elevations of these features relative to the surrounding landscape and thus allows the direct measurement of feature volumes heights. On the other hand, it is less computationally expensive and easier to implement than the kriging based filtering suggested by Humme et al. (2006) if an efficient workflow for data processing is applied.

First results

DEMs and LRMs contain data of absolute elevation and local topographic anomalies, respectively. Therefore, archaeological prospection using these data can only detect features which are characterised by topographic peculiarities such as linear, circular or rectangular convexities or concavities. However, LRMs allow the visualisation and detection of very subtle features which differ only by 0.1 or 0.2 m from their surroundings. Such subtle features are generally not recognisable in the field, in particular under forest cover (which only has a limited impact on LIDAR).

Archaeological features which are particularly well recognisable are kiln podia (charcoal production sites, Figure 2a), agricultural terraces and ridge and furrow fields (Figure 2b), mining and quarrying sites, sunken roads (Figure 2c) as well as linear earthworks. Potential burial mounds (Figure 2d) are also recognisable; however, due to their similarity with some natural surface forms their identification must be considered less reliable.

Project progress

The project aimed at the LIDAR-based archaeological prospection of Baden-Württemberg was launched in May 2009. As no software was available that allowed the efficient management of the enormous amounts of data (> 1 TB of LIDAR point cloud data in > 160,000 separate files) and the implementation of the intended workflow, graphical user interfaces for data management and data processing were implemented in VBA (Visual Basic for Applications). DEM interpolation and contour line generation was performed using ENVI. GlobalMapper is used for visualisation and mapping.

During the first phase of the project, prospection is concentrated on two regions: (i) the Schönbuch, a forest region in central Baden-Württemberg and (ii) the southern Black Forest and Upper Rhine region in southwestern Baden-Württemberg (Figure 3). The Schönbuch region has a surface area of 600 km² with elevations between 281 and 646 m. Here, the LIDAR-based prospection has been completed, and 2513 potential archaeological sites were mapped. This compares with 1966 previously known sites and find spots. The southern Black Forest and Upper Rhine study region has a surface area of 2500 km² and elevations ranging from 210 to 1493 m. It is characterised by steeper and much more diverse relief than the Schönbuch region. Until the end of January 2010, prospection of 1300 km² in the southern Black Forest and Upper Rhine region have resulted in 23,084 potential archaeological sites compared with 2071 sites and find spots registered in the archaeological data base. However, it has to be noted that the number of sites and find spots in the data base does not yet fully represent the current state of knowledge because the compilation of the data base is still work in progress for this region.

Taken together, 1900 km² (5.5 % of the area of Baden-Württemberg) have been prospected since the completion of program development/implementation of the data processing, resulting in a total number of 25,597 pre-modern anthropogenic features and potential archaeological sites. This compares with a total number of 4037 archaeological sites and find spots previously contained in the archaeological data base for the prospected area.

Conclusions

Local Relief Models (LRMs) representing topographic anomalies can be extracted from LIDAR-based high-resolution DEMs. LRMs are a valuable tool for the mapping and prospecting of archaeological features such as burial mounds, linear and circular earthworks, sunken roads, agricultural terraces, ridge and furrow fields, kiln podia and mining sites. They provide further possibilities for analysis such as local elevation profiles and volume measurements. An ongoing project aimed at the spatially complete archaeological prospection of the German state Baden-Württemberg is presently documenting the feasibility of using LIDAR-based DEMs and LRMs for very large areas. First results of the project show that LIDAR-based archaeological prospection can lead to a five- to tenfold increase in the number of potential archaeological sites and thereby make a tremendous contribution to the documentation and protection of the archaeological heritage.

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Figures

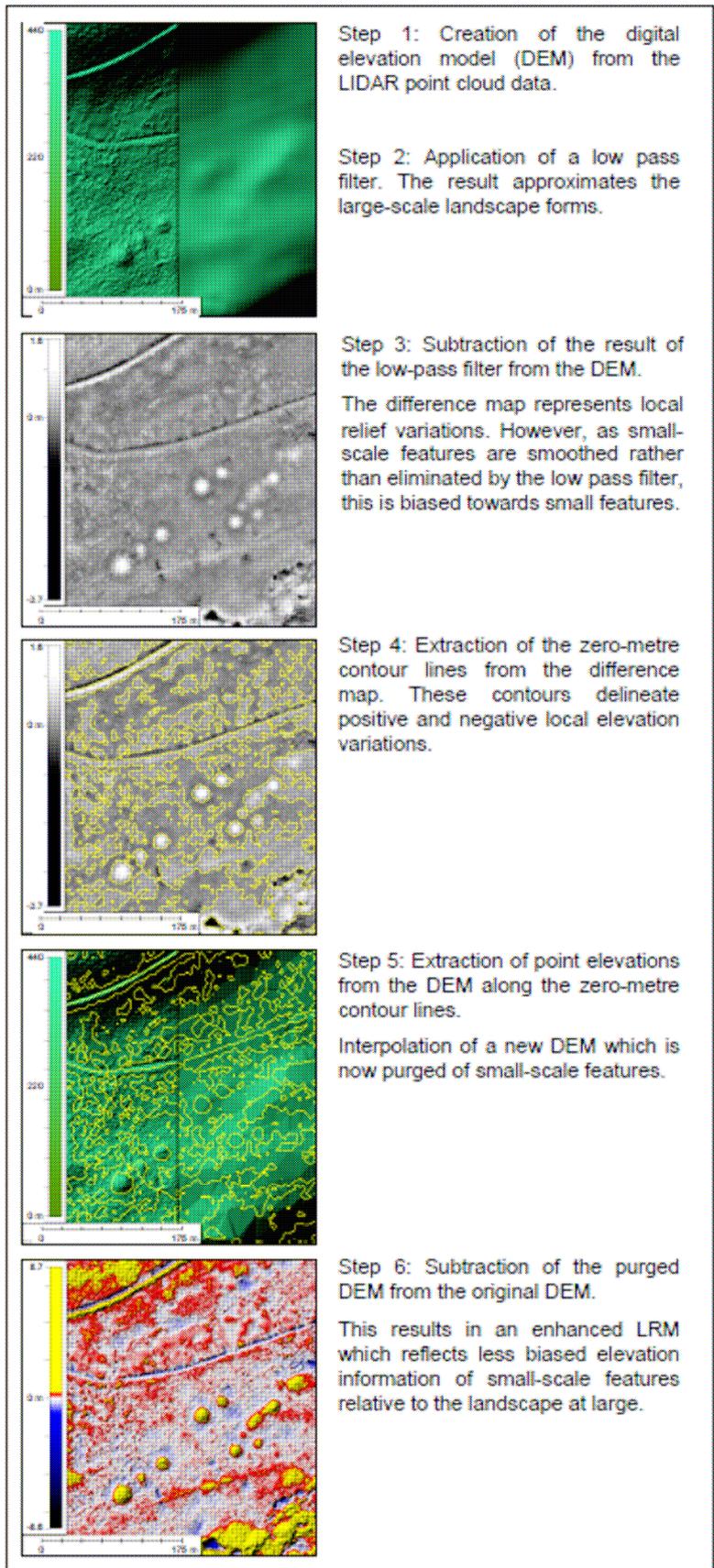


Fig. 1 – Workflow for the creation of Local Relief Models.

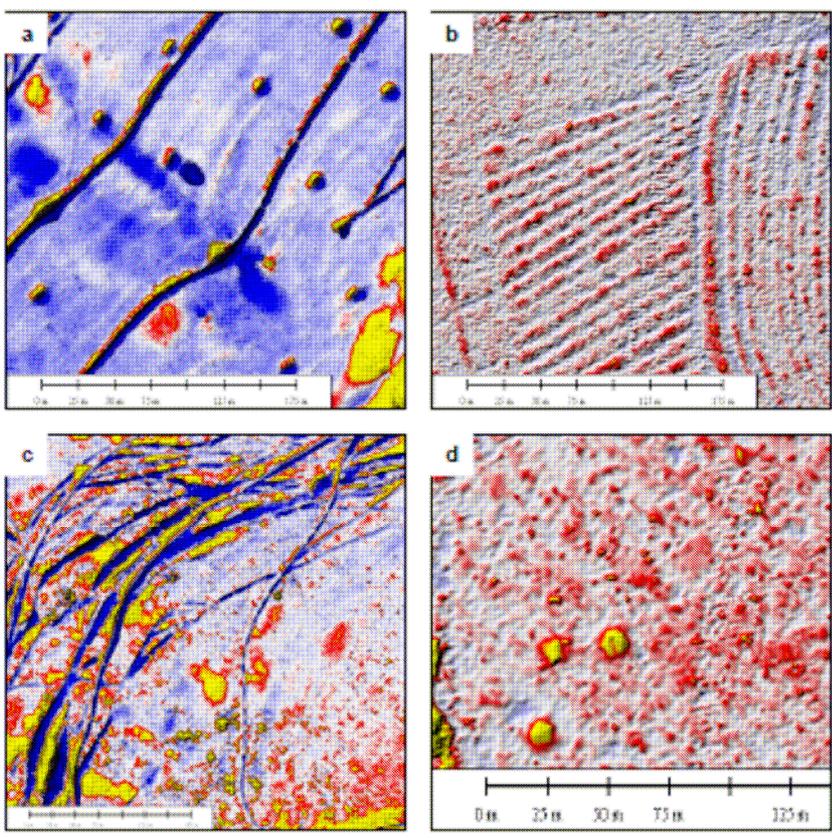


Fig. 2 – Examples for LRM representation of archaeological sites: (a) kiln podia, (b) ridge and furrow fields, (c) sunken roads, (d) burial mounds.

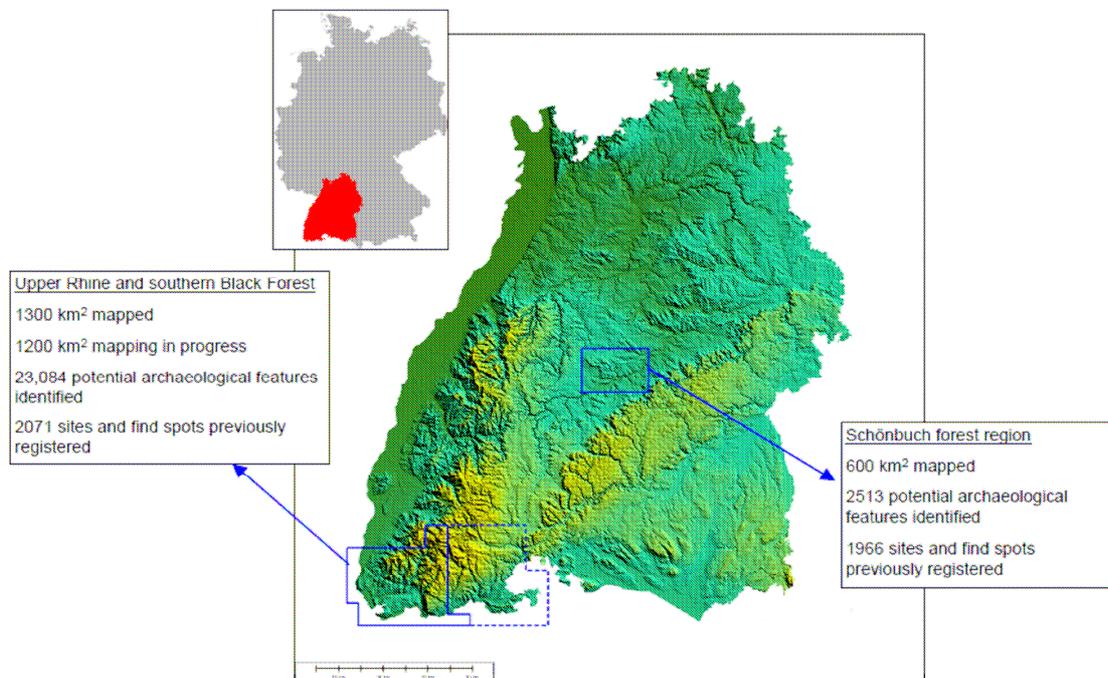


Fig. 3 – Progress of the archaeological mapping project in Baden-Württemberg.

Integrated geophysical survey to characterize the subsurface properties below and around the area of Saint Andreas church (Loutraki, Greece)

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Abstract: Urban archaeological geophysics is an emerging field that focuses on the effective geophysical exploration of urbanised areas in order to provide specific solutions concerning the preservation of cultural monuments located in urban territories. This work presents an integrated application of the Ground Penetrating Radar (GPR) and Electrical Resistivity Tomography (ERT) methods to effectively map the complex settings of the physical environment below and around the area of Saint Andreas church in Loutraki (central Greece). The cultural value of Saint Andrea's church is significant but unfortunately it has been severely damaged by the Alkyonid earthquake in 1981. The main purpose of this geophysical investigation was to provide the necessary feedback concerning the ground subsurface properties for the future restoration of the monument. High resolution ERT and GPR data were gathered in various parts inside and outside the area of the church. Two and three dimensional inversion algorithms were used to reconstruct the true subsurface resistivity while the GRP signals were enhanced by the application of advanced filters. The geophysical campaign indicated: i) a smoothed stratigraphy below the surface in the interior of the church, ii) rock masses which probably come from the limestone side detritus, iii) the location of the upper surface of the water table at 1.2-1.5 m below the road surface. These results can provide significant information in order to design the future restoration works of the church. The combined use of ERT and GPR are adequate to reconstruct the complex subsurface properties encountered in this urban setting, manifesting the significant contribution of urban geophysics in restoration approaches of monuments that exhibit significant cultural value.

Key words: Electrical Resistivity Tomography, Ground Penetrating Radar, urban geophysics, Saint Andreas church, Loutraki, Greece

Introduction

The rich historical background in urban areas lies mainly on the large number of observed monuments at various sites. Sometimes there are even more monuments in the subsurface that need further investigation and which can also add to the cultural value of the urban centers. In other cases, human construction works or natural disaster incidences could influence the integrity of the monuments which need a systematic conservation.

Nowadays, the relatively new study field called "urban geophysics" has emerged. Urban geophysics focuses on the geophysical exploration of urban areas and existing monuments in order to investigate and characterise the subsurface properties of urbanised environments and provide effective solutions concerning either the detection or the preservation of cultural monuments located in urban territories.

A geophysical survey in an urban area and especially inside an existing building is not easy and whatever the operation might be, certainly it has to be non-invasive. The highly heterogeneous nature of the upper layers, due to the existence of man-made objects in addition to the ambient noise caused by electrical currents and electromagnetic radiation can have an undesirable influence on the geophysical measurements. Furthermore, the need for a high-resolution geophysical survey conducted in limited time, sometimes combined with restricted site access imposes additional difficulties. All of the above factors prove the necessity of developing innovative research methods in effectively approaching the geophysical exploration of existing monuments in urban territories.

Among the geophysical techniques, Ground Penetrating Radar (GPR) and Electrical Resistivity Tomography (ERT) appear to be the most suitable techniques for reconstructing the complex subsurface properties in urban areas as they are rapid, cost-effective and non-invasive. GPR has been used successfully to survey the interior of existing monuments like churches (TSOKAS et al. 2007, GARCIA et al. 2007, BARILARO et al. 2007, RANALLI et al. 2004, LINFORD 2004, PIRO et al. 2003).

The application of GPR inside an existing building is very suitable as the technique is fully non-invasive and the floors are usually flat, which ensures the continuous movement of the antennae. In cases that the concealed structures might be buried relatively deep or the upper conductive layers prevent the deep penetration of radar signals, the ERT method provides a flexible and alternative solution (NEGRI et al. 2008, TSOKAS et al. 2008).

This work presents an integrated application of the surface GPR and ERT methods to effectively map the complex changes of the physical environment below and around the area of Saint Andreas church in Loutraki (central Greece). The goal of this survey was to provide the necessary feedback to the conservators and engineers by exploring the possibility of the existence of voids or fractures below the foundations of the structure.

Area of Investigation: Saint Andrea's Church, Loutraki

Saint Andrea's church is located along the seaside at the north-west edge of Loutraki village (Fig. 1). The church has been constructed next to a rock incline composed of the Gerani limestones. These formations appear with severe tectonic characteristics due to the seismic activity in the broader area. A normal fault is directed along the coast seaside and karstic springs spurt from the limestone side detritus. The spring of Oikonomou belongs to this kind of springs (Fig. 2) as it is located at the south wall of the church.

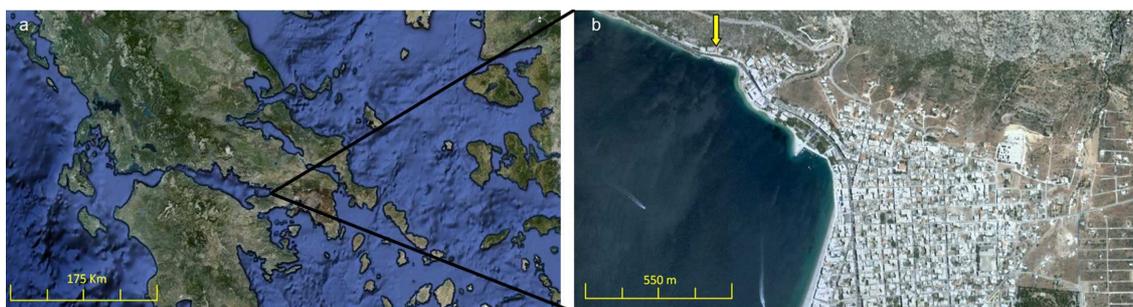


Fig. 1 – a) Satellite image of the central Greece indicating the location of Loutraki village. b) The yellow arrow indicates the location of Saint Andrea's church at the north-west side of Loutraki.

The church is a relatively small three-aisled basilica with cupola and its external dimensions are 8.70 m and 9.50 m in the north-south and east-west direction respectively, while its height reaches the 8.95 meters. The church was constructed in 1345 by the emperor John VI Catakouzenos in the memory of Saint Andrea's persecution and its sanctuary is divided into three parts (Fig. 2).

The cultural value of the monument is significant, as according to the legend, the stairs at the north side of the church lead to the entrance of a small cave, which was used as a hideaway by Saint Andreas when he was pursued by Romans. The church has been severely damaged by the Alkyonid earthquake in 1981. Since 1962 the Greek Ministry of Culture has declared the church as a preservable monument and is studying a restoration plan of it.



Fig. 2 – View of Saint Andrea's church from the south. The building in front of the church hosts Oikonomou spring.

ERT and GPR survey design

A total area of more than 500m² was surveyed in a three-day field project during April of 2007 employing Ground Penetrating Radar (GPR) and Electrical Resistivity Tomography (ERT) methods. Both Dipole-Dipole and Wenner-Schlumberger arrays were employed to collect the ERT data along eight individual profiles. The inter-electrode spacing was $a=1\text{m}$ for all the lines. In order to enhance the resolution of the final resistivity models and obtain an improved 2-D subsurface picture the combination of data with electrode spacing 1a, 2a, 3a and $N=8$ were collected, where N is the ratio of the distance between the A-M electrodes to the M-N dipole length (A: current electrode; M, N: potential electrodes). The electrodes were connected through a multicore cable to a multiplexer (Switch Pro), which was then connected to the measuring apparatus (Syscal Pro).

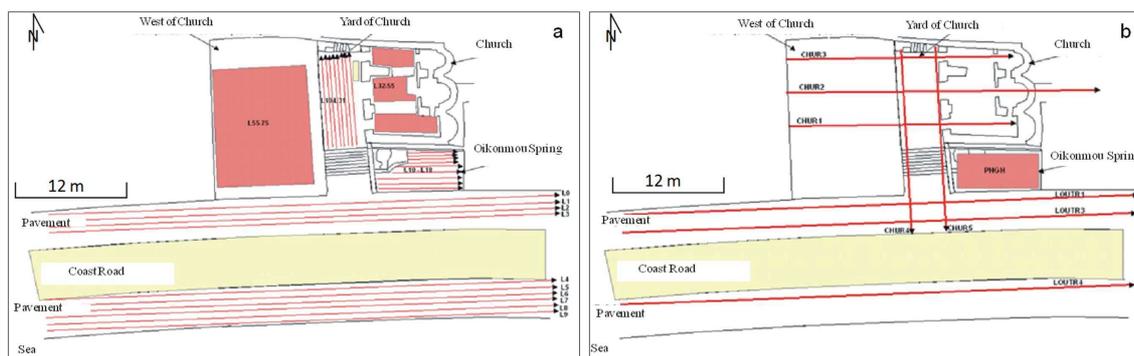


Fig. 3 – a) Ground Penetrating Radar transects inside and around the area of the church. b) Location of the eight Electrical Resistivity Tomography profiles.

Figure 3b shows the layout of the lines that were completed in the area around the church. Lines Loutr1, 3 and 4 were completed at the pavement in front of Oikonomou spring in a west - east direction and each one had a length equal to 47 meters. Lines Chur1, 3, 4, 5 had the same total length (23 m) and the length of line Chur2 was 32 meters. Lines Chur4 and 5 were laid out in front of the main entrance of the church going down the stairs, while profiles Chur1, 2 and 3 originated at the west yard and crossed the interior of the church. In order to explore the subsurface properties inside the building that hosts Oikonomou spring, a complete 3-D surface ERT survey using the dipole-dipole and pole-dipole arrays was implemented. The 84 electrodes were laid out on a 11m x 4.5m rectangular grid, every 1 and 0.75 meters in the X and Y direction respectively (Fig. 4). Bentonite contact electrodes were used throughout the ERT survey. The use of this kind of electrodes avoids the need to insert metal electrodes into the ground, rendering the ERT as a fully non-destructive method applicable inside historical monuments (ATHANASIOU et al. 2007).

A dense grid of GPR profiles in six different areas around and inside the church were conducted using the Noggin Plus unit with the 250 MHz antennas. The GPR survey was focused on the pavement in front of the building that hosts Oikonomou spring and the pavement south of the coastal road. The yards in front of the entrance and at the west of the church were also surveyed. The subsurface below the building of Oikonomou spring and the church was also explored with the GPR. Almost 75 GPR profiles of variable length, according to the maximum dimensions of the investigated area were gathered. The parallel lines were placed every 0.5 meters in a local coordinate system and measurements were recorded every 5cm along each line. The specific survey mode was sufficient to map the subsurface properties with adequate resolution. Furthermore an experimental line was completed along the wall at the south side of the church using the 500 MHz antenna. Figure 5 shows details of the GPR survey inside and around the church.



Fig. 4 – Surface electrode layout inside the building of Oikonomou Spring in order to carry out the 3-D resistivity measurements. The yellow circle indicates the benonite contact electrodes.



Fig. 5 – a) Details of the GPR survey at the yard in front of the church entrance. b) GPR survey on the wall at south side of the church.

ERT and GPR data processing procedure

A systematic workflow was used to process the collected ERT data. Firstly, the noisiest apparent resistivity measurements, mainly due to poor ground contact, were removed from all of the individual pseudosections. The dipole-dipole and Wenner-Schlumberger data for each line were combined and a two-dimensional (2-D)

resistivity inversion algorithm (LOKE & BARKER 1995) was used to produce a common 2-D resistivity model. The 2-D inversion scheme performs an iterative optimization based on a 2.5-D finite element modelling scheme. The 2-D algorithm is fully automated and performs smoothness constrained inversion (SASAKI 1992). The ERT data collected from the building of Oikonomou spring were combined into a single data file and processed with a three-dimensional (3-D) resistivity inversion algorithm (LOKE & BARKER 1996), which is based on an iterative 3-D finite element scheme and a smoothness constrained inversion routine (SASAKI 1994). The inversion scheme, for both the 2-D and 3-D cases, applies a smoothness constraint on the model correction and not on the final model resistivity values. As a result it can fully cope with the high resistivity contrasts encountered in urban environments, while at the same time achieves stability and reduces inversion artefacts.

A common strategy was also followed to process the GPR data. The first peak was determined in order to define the initial useful signal from each line. This determination was based on the intensity percentage of the first reflected wave (5-30%). The line equalization based on the selected first peak was followed and this procedure tried to bring the first reflections of each line in a common starting time. Then the application of AGC, Dewow and DCshift filters enhanced the reflected signal, while the rejection of the background noise and the data smoothing was accomplished by a trace-to-trace averaging filter. Finally, horizontal depth slices at different depth levels were created by the original vertical sections assuming a velocity for the electromagnetic waves equal to 0.1m/nsec.

Results

Figure 6 shows the ERT and GPR maps of the combined geophysical survey inside the building of Oikonomou spring (Fig. 4). The results are presented as horizontal slices in increasing depth. Figure 6 (b) shows an evident absorption of the GPR electromagnetic energy (blue colors) mainly due to the water content of the subsurface. Some strong reflections at the south-west side of the area in the depth layers up to 2 meters below the surface indicate the continuation to the south of the void which corresponds to the spring. In general, the strong reflection anomalies are isolated and they do not indicate extensive voids. On the other hand these anomalies represent small parts of the cracked bedrock. Similar results arise from the combined dipole-dipole and pole-dipole 3-D resistivity inversion model (Fig. 6a). The superficial layers, up to 1.5 meters below the surface, show some isolated high resistivity targets, while in deeper layers the surface is saturated with water, as the low resistivity values indicate.

The geophysical investigation on the pavement in front of the building that hosts Oikonomou spring showed similar results with those inside the building. All the GPR and ERT profiles that completed in the area resulted comparative outcomes, similar to what it is indicated by the results of line L2 (GPR) and Loutr1 (ERT) (Fig. 7). The isolated superficial reflections (yellow arrows) at 29 m and 40 from the beginning of the line were caused by the presence of water pipes or other cables. Some other reflections that appear deeper in the radargram probably do not comprise a significant alteration of the subsurface (Fig. 7a). The 2-D resistivity inversion model of line Loutr1 shows isolated rocks in the superficial layers, which are located in a saturated medium, since the water table appears at the depth of 1.3-1.5m below the ground surface. In most places along the line the bedrock appears in depths greater than 6m except its superficial appearance to the east (Fig. 7b).

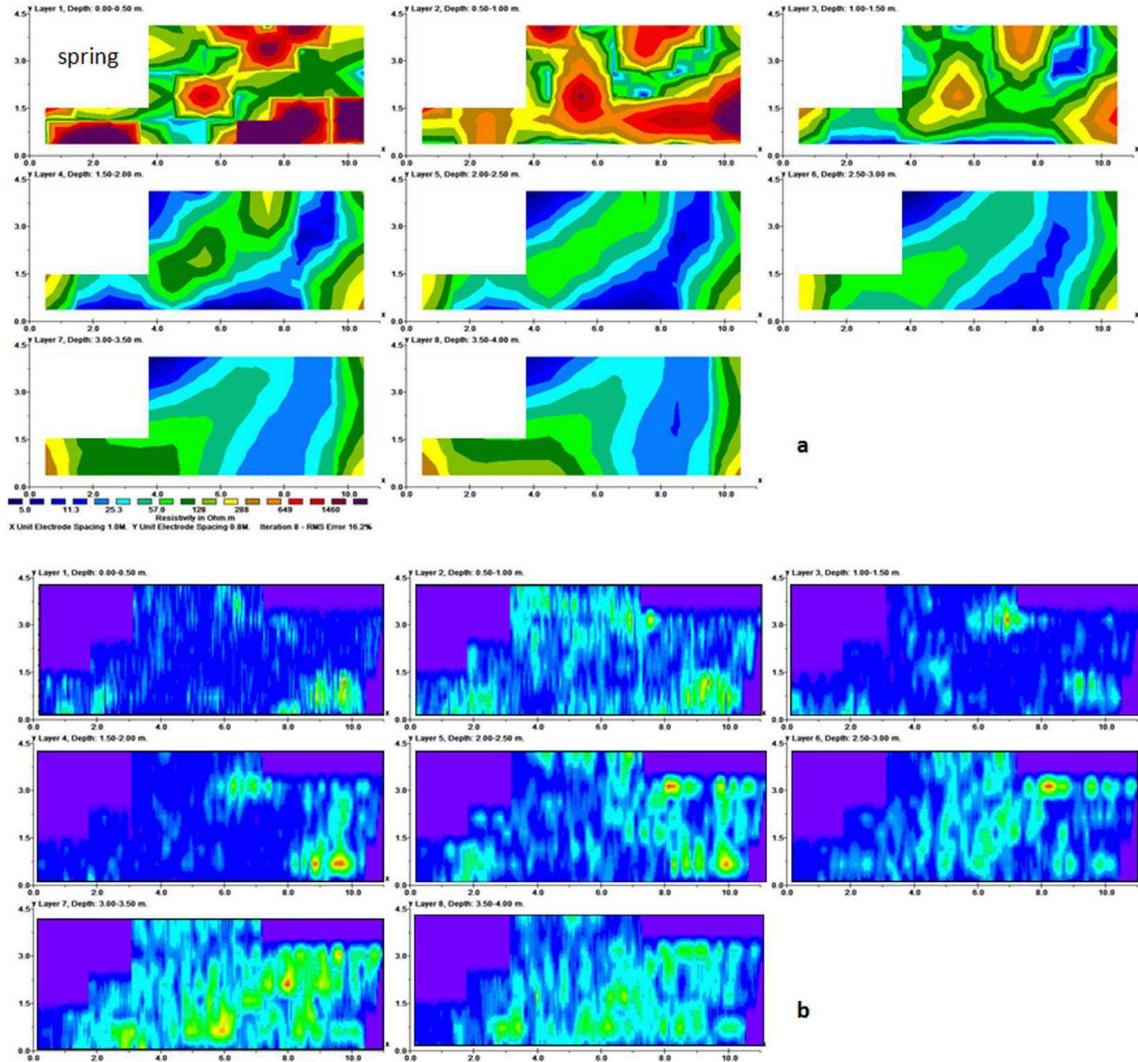


Fig. 6 – a) 3-D resistivity model from the combined inversion of the Dipole-Dipole and Pole-Dipole data inside the building of Oikonomou Spring. b) GPR depth slices of the subsurface inside the building of Oikonomou spring. The warm colors indicate strong reflections.

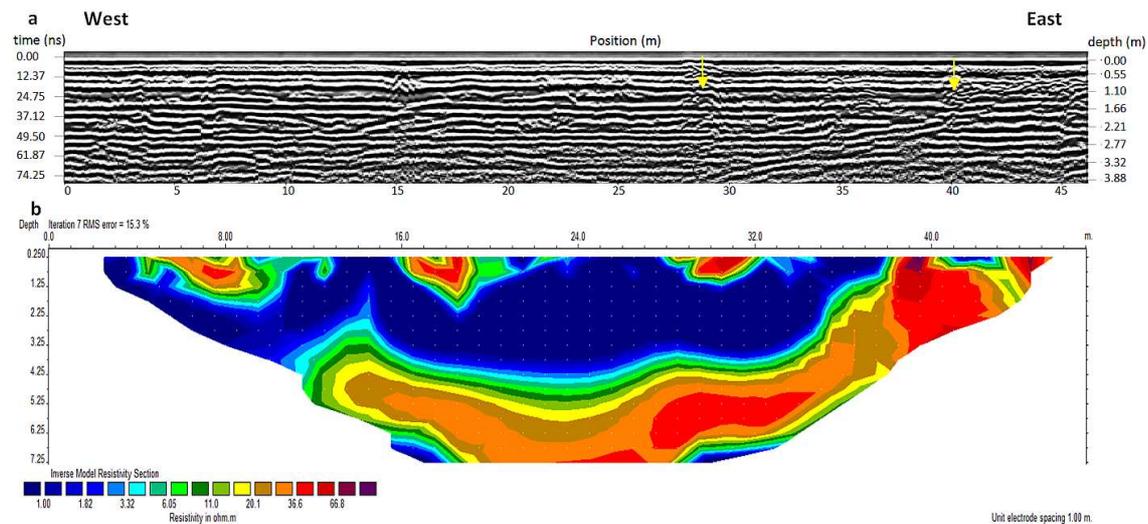


Fig. 7 – a) GPR profile along the line L2 on the pavement in front of Oikonomou spring. b) 2-D Dipole-Dipole and Wenner-Schlumberger combined resistivity inversion model for the line Loutr1.

The area to the west has an elevation difference of almost 2m in relation to level upon which the church was constructed (Fig. 5a). A number of parallel profiles were completed in this area and the slices for depths 0.80m and 2.00m are shown in Fig. 8. A rectangular structure appears at the upper layers (up to 1 m), probably related to the remains of a garden or some other modern activities that have taken place in the area. Again the isolated strong reflections are the most interesting findings in the area. Comparing the signal from the location (x=1.5 E, y=7-8 N) where there is a visible outcrop of a rock mass, then all the strong reflection anomalies could be correlated to cracked rocks that have fallen from higher levels of the hill at the north.

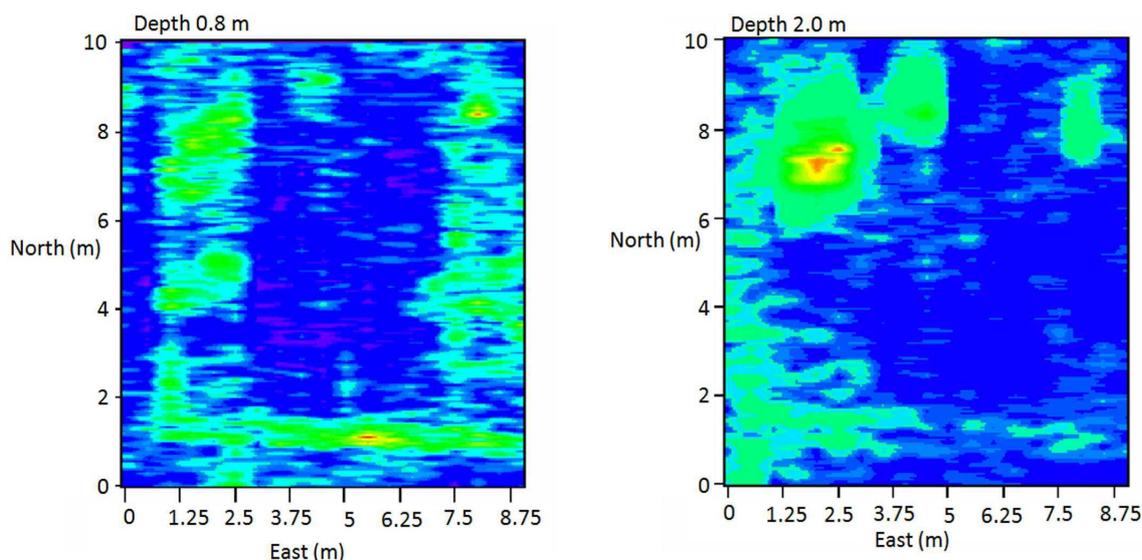


Fig. 8 – GPR slices of 0.8 and 2.0 m at the area west of the church.

The entrance of the church is located to the west of the building that hosts Oikonomou spring going up for a few stairs (Fig. 5a). The GPR slice for the depth 1.6 m below the ground surface at the church yard shows a strong reflection at the north of the excavation trench (grey rectangular), at the south-west and at the north-west (Fig. 9a). The general impression is that these isolated reflections, which are not related to each other, are probably caused by rock parts that have fallen from the upper levels of the hill to the north. The north-south ERT profile Chur5 supports the GPR conclusions (Fig. 9b). The largest part of the yard has high resistivity values in the shallow depths, which decrease as the depth reaches the level of the road. The extension of the rock parts is also visible to the south below the yard stairs.

The geophysical survey was also conducted inside the church where the GPR signals suggest a generally uniform stratigraphy without strong reflections and thus the absence of voids below the church at least until the depth of 3 m. Only a strong reflection is located at the centre of the church in front of the holy place which is probably related to an isolated rock part (Fig. 10a). High resistivity areas are located at the trench and the yard of the church along the ERT profile Chur2. The high resistivity values to the east of the church are related to highly inhomogeneous surface material. The most important resistivity anomaly is located at the horizontal location of 17-21 meters from the west and at the depth of 3.5 m below the church. This anomaly is related to the strong GPR reflection pinpointing an isolated rock part.

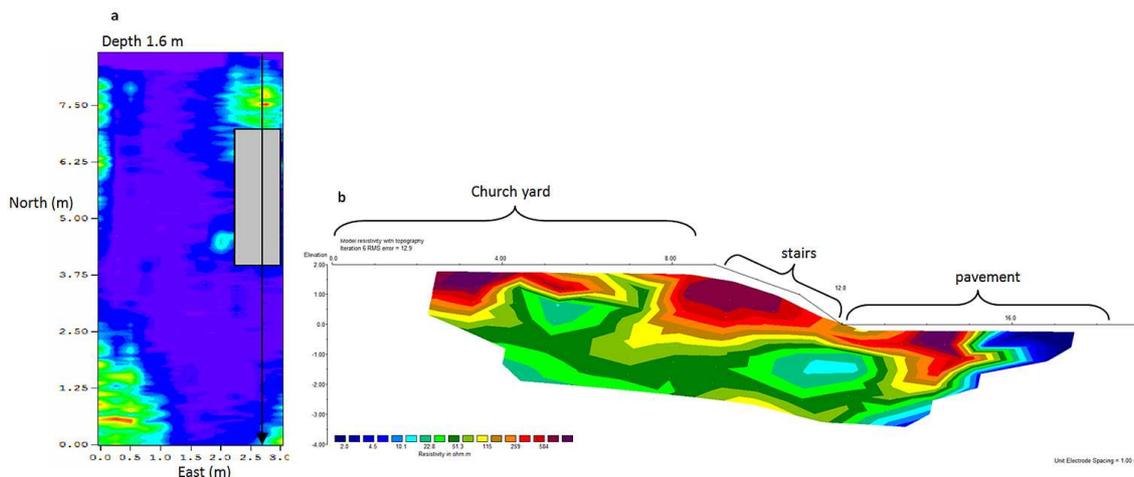


Fig. 9 – a) GPR slice at depth 1.6 m at the church yard. The black arrow indicates the position of the ERT profile Chur5. b) 2-D Dipole-Dipole and Wenner-Schlumberger combined resistivity inversion model for the line Chur5.

Finally, an experimental east-west profile was measured along the wall at the south side of the church (Fig. 5b) using the 500 MHz antennas and at a distance of 1.5 m below the church ground floor. The results have relatively increased levels of noise and the detected weak reflections are probably due to the internal changes of the wall, suggesting different phases of construction of the church.

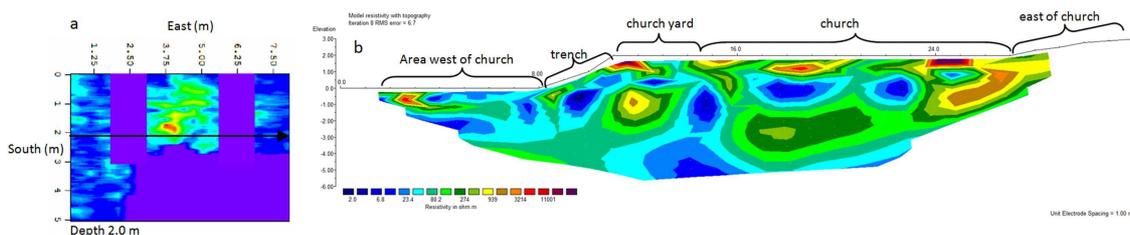


Fig. 10 – a) GPR slice at depth 2.0 m inside the church. The black arrow indicates the position of the ERT profile Chur2. b) 2-D Dipole-Dipole and Wenner-Schlumberger combined resistivity inversion model for the line Chur2.

Conclusions

The main conclusions arising from the geophysical campaign in the area around and inside the church of Saint Andreas can be summarized in the following:

- Most of the high resistivity anomalies and strong reflections detected at the south pavement and the yard outside the church were caused by rock masses which probably come from the limestone side detritus at the north.
- There are no indications of extensive voids in depths less than three meters below the surface in the interior of the church.
- A rock mass, which corresponds to the continuation of the bedrock below the church, is located at the centre of the church and in front of the holy place.
- Isolated rock masses were detected at the pavement south of the building that hosts Oikonomou spring and at the yard at the west of the church.
- The yard of the church was constructed on rock masses that have fallen from the north. The limestone which was revealed in the excavation trench in the church yard continues to the north.

- The limestone bedrock appears in depths larger than 6 m from the road surface as it was indicated by the 2-D resistivity tomographies at the pavement south of the church.
- The upper surface of the water table is located 1.2-1.5 m below the road surface. Furthermore, the results suggested that there are no strong indications of voids in the upper levels of the subsurface in the building that host the spring of Oikonomou.

The above results can provide significant information that can be used in the stage of designing an effective manner for the future restoration works of the church. This case study signified that the combined use of ERT and GPR methods seems to be adequate to reconstruct the complex subsurface material properties encountered in the urban settings. In general urban geophysics provides a valuable tool at the stages of restoring monuments which exhibit significant cultural value.

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Virtual 3D Reconstruction of the East Pediment of the Temple of Zeus at Olympia –

A practical example explaining difficulties of data collection in the field

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Abstract: The arrangement of the five central figures of the east pediment of the temple of Zeus at Olympia has been the subject of scholarly debates since the discovery of the fragments more than a century ago. Most recently the author has started a project to approach this controversy in a new way, by producing a virtual 3D reconstruction of the group. Digital models of the statues are produced by scanning the original fragments and by reconstructing them virtually in order to test the feasibility and aesthetic effects of the different reconstructions. The paper focuses on the various technical difficulties encountered during the scanning campaign in the Museum of ancient Olympia (23.08 – 03.09. 2009) and gives an overview of the work in progress.

Keywords: 3D scanning, classical Greek marble sculpture

The subject

The temple of Zeus at Olympia was built in the first half of the 5th century B.C. (ca. 475-455). Its sculptural decoration consists of two pediments and twelve metopes. Given the large size of the building itself, the sculptures were all well over lifesize and were made of white parian marble. A large number of fragments survive and are conserved in the Archaeological Museum of Olympia and in the Musée du Louvre (Paris). Most of them are quite well preserved and are depicted in practically every handbook on Greek art or on ancient art in general, because nowadays they are generally considered to be one of the most important and most magnificent works of ancient Greek art. They have been thoroughly studied since their discovery in the 1880's, but they still pose some important questions, as indicated by the growing number of monographs and scholarly articles related to them (e.g. TREU 1897, ASHMOLE-YALOURIS 1967, SIMON 1968, SÄFLUND 1970, HERRMANN 1987, KYRIELEIS 1997, BARRINGER 2005, WESTERVELT 2009). The most recent debate has started with a series of publications by the author (PATAY 2004, PATAY 2005, PATAY 2006, PATAY 2008) and concerns the interpretation of the east pediment (Fig. 1), which involves the problematic issue of the correct reconstruction of the central group as well.



Fig. 1 – Fragments of the east pediment. Actual arrangement in the Archaeological Museum of Olympia. (Photo: author)

The problem

The arrangement of the five central figures of the east pediment of the temple of Zeus at Olympia has been the subject of scholarly debates since the discovery of the fragments more than a century ago (HERRMANN 1987, PATAY 2008). The basic problem is that the fragments themselves can be arranged in four substantially different ways and there are no obvious clues for choosing the most probable one (Fig. 2).

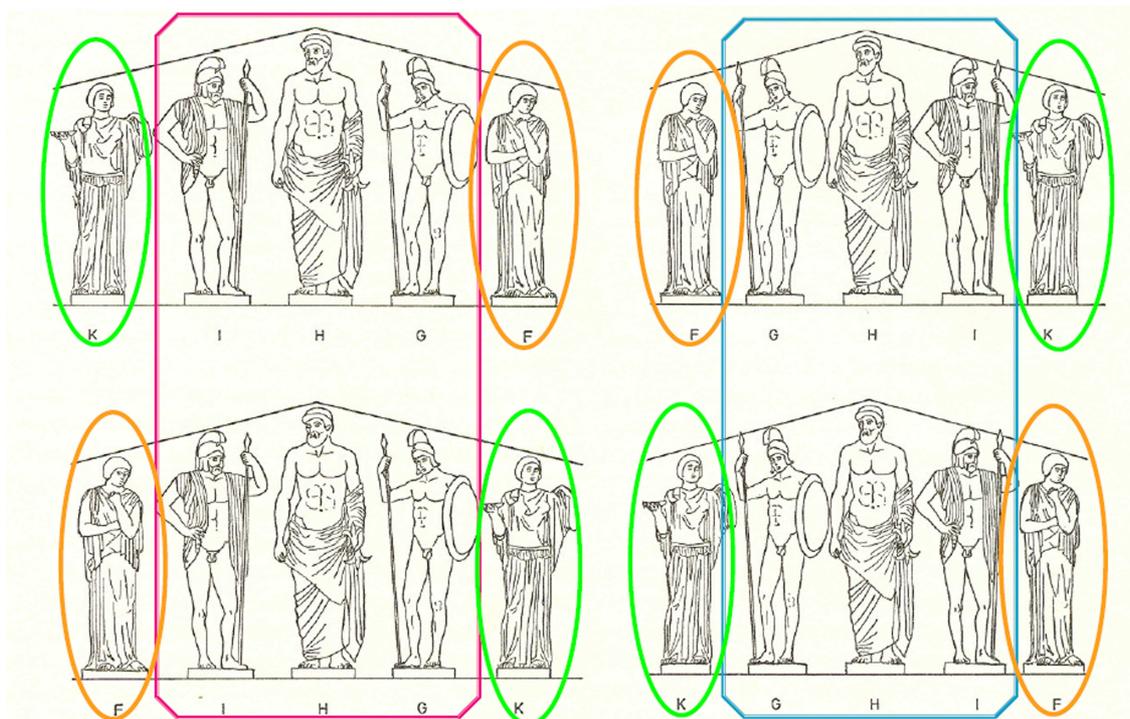


Fig. 2 – Schematic reconstruction drawings showing every conceivable arrangement of the five central figures (usually referred to as F, G, H, I and K). Different colours highlight the differences between the four variants. (After Herrmann 1987)

There is a fairly detailed description of the group by Pausanias (Description of Greece V 10, 6-7), who saw it in the 2nd cent. AD, but his text is not conclusive regarding the precise arrangement of the figures (he does not specify how to understand his indications „to the left“ and „to the right“ of the central figure). The findplaces are not unequivocal either, since the pieces were scattered around the temple by an earthquake in the 6th cent. AD and the fragments were subsequently reused in medieval buildings. In sum, there are four substantially different arrangements, all of which have already been selected by certain scholars for various aesthetic, technical and other considerations. Most often the reconstructions were presented in simple drawings, ignoring the three-dimensional form of the statues and the results of an early experiment with miniature 3D models (TREU 1897, 120) are nowadays equally ignored.

The project

Since experimentation with the precious and monumental original fragments is out of question and life-size plaster casts are similarly ill-suited for this purpose, it seemed to be reasonable to apply the latest 3D

scanning technology to the problem. The aim of the project is to test the practical feasibility and aesthetic effects of the possible arrangements with 3D models of the reconstructed statues. The digital models are produced by scanning the original fragments and by reconstructing them (i.e. completing their missing limbs and armour) virtually. Scanning was done with Breuckmann smartSCAN Duo structured light scanner by Tondo Ltd., the reconstruction will be attempted with different software products (e.g. Poser 8 by Smith Micro and Leonard3Do by 3DforAll).¹⁵⁵ The scanning campaign was carried out with the permission of the 7th Ephorate of Prehistoric and Classical Antiquities in Greece and in close collaboration with the German Archaeological Institute at Athens (conducting the excavations on the site for more than 125 years). Financial support is provided by a research fund of the Norway Grants and the Hungarian National Research Fund (OTKA).

Difficulties encountered

The high precision 3D scanning of monumental marble sculpture is a difficult task. There have been only two similar projects so far, the Digital Michelangelo (1997-2007) directed by Prof. M. Levoy (Stanford University) and the Trier Constantine (2007) carried out by ArcTron Ltd.¹⁵⁶

The first problem was financial: Our budget was much smaller than in similar cases, the plan itself being equally ambitious and the difficulties comparable or in some cases even insurmountable. In addition, there were only some 3-5 months left for selecting the affordable and state-of-art technology, equipment and company. These difficulties were overcome by intensive consultations with specialists, negotiations with different companies in and outside Hungary and finally by testing the equipment and the skill of the technicians in the collection of Greek and Roman Antiquities of the Museum of Fine Arts (Budapest). As a result two experienced technicians of Tondo Ltd. (Budapest, Hungary) were employed and the scanning was carried out in the Museum of Olympia from 23.08 to 03.09. 2009.

The difficulties encountered during the data capture resulted primarily from the monumental scale (1,5-2 times lifesize) of the fragments exhibited in the main hall of the museum.¹⁵⁷ The upper parts were not accessible with the scanner mounted in the usual way on a tripod but only with a special equipment, the so called Jimmy Jib (Fig. 3).¹⁵⁸ This type of crane is usually employed in producing movies and has never been employed for 3D scanning. It was tested in Budapest and proved to be practical for the present task: it can be transported and assembled relatively easily, its handling is equally easy, and it does not present any

¹⁵⁵ For more information on these see <http://www.breuckmann.com>; <http://leonar3do.com>; <http://my.smithmicro.com/win/poser/index.html>.

¹⁵⁶ See <http://www-graphics.stanford.edu/projects/mich> and <http://www.arctron.de/3D-Vermessung/3D-Laserscanning/Beispiele/Konstantin/PresseArcTron3D.pdf>.

¹⁵⁷ Small fragments, which are not exhibited, have also been scanned. The difficulty with them was not their monumental scale but the fact that they were hardly traceable in the storerooms of the museum. One fragment, published more than a century ago (TREU 1897 fig. 59) has seemingly disappeared.

¹⁵⁸ <http://www.jimmyjib.com>; <http://www.jimmyjib.co.nz/default.asp>.

danger for the precious originals. The workflow has thus been optimized, because there was no need to build a massive scaffolding.



Fig. 3 – Scanning the fragments of the east pediment with Jimmy Jib crane (Photo: author).



Fig. 4 – Iron bars used to keep the fragments in position. This arrangement close to the wall prevented the scanning of the rear sides of the figures. (Photo: author)

Since the weight of the large fragments is enormous, they are fastened to the wall with several massive iron bars (Fig. 4). As a consequence, the fragments are absolutely unmovable and due to their alignment close to the wall their rear sides were difficult to reach with the scanner, some parts proved to be inaccessible indeed. As these parts were in most cases only roughly hewn from the block, their exact rendering is actually not relevant for the reconstruction. Moreover, they are sufficiently documented in drawings and photographs, and can therefore be approximately completed during the processing of the scans.

Last but not least, the scanning was made difficult by the restricted working hours. Since the museum of Olympia attracts a very large number of visitors from all over the world, it is open every day from 8 a.m. to 8 p.m. (except for Monday, when it is open from 13 to 20 p.m.). Moreover, the fragments of the pediments of the temple of Zeus are world-famous pieces and belong to the main highlights of the museum, so we were allowed to scan only from 8-12 p.m. In spite of these rather narrow time limits, our team was able to complete the task of scanning all fragments belonging to the east pediment (13 human figures and two four-horse chariot teams) in two weeks.

Work in progress

Triangulation, meshing and smoothing of most scans is already completed. This process required more than 4 months of constant work by an assistant (Mr. D. Bajnok, cand. phil.) trained especially for this task. Data voids, which are sometimes of considerable size (due to the inaccessibility of the rear sides of the statues) are in most cases also filled in by using Geomagic. These artificially completed parts are clearly visible on the models (Fig. 5). Currently every fragment of the five central figures is processed and the resulting 3D models are ready for the virtual reconstruction.

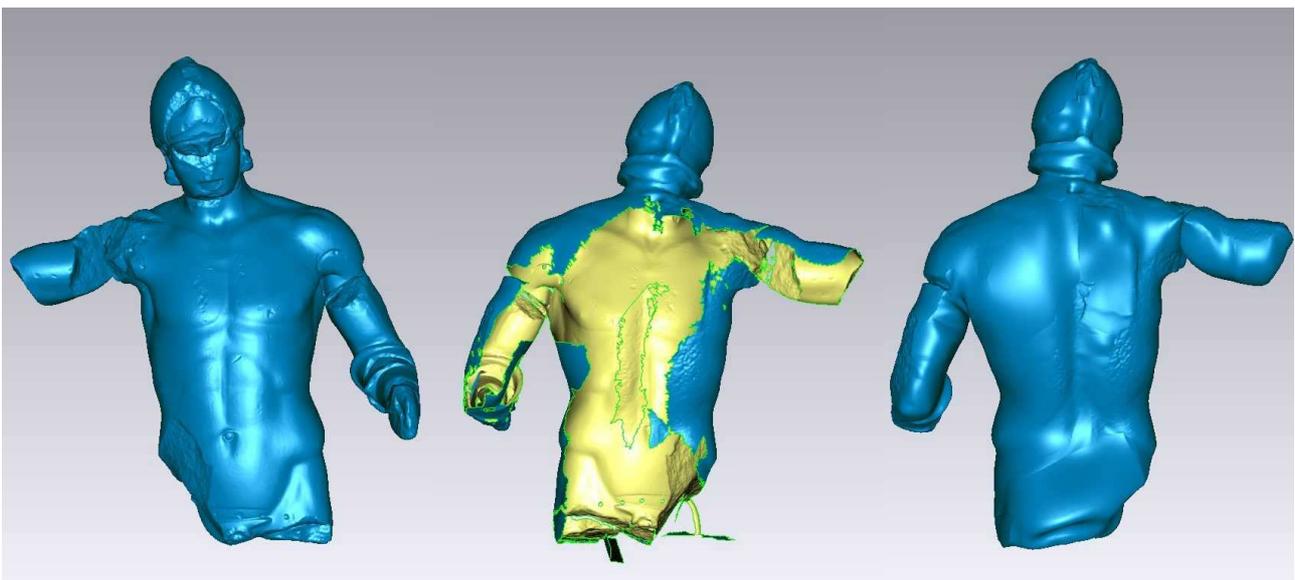


Fig. 5 – The scanned torso of figure G of the pediment. Front view (left) and back view (middle) showing data voids resulting from the close alignment to the wall. Completed 3D model of the piece on the right.

Missing parts (limbs, heads, armour, etc.) are currently being completed and the reconstruction of the pediment itself will hopefully follow soon. We try to make use of different softwares in order to select the most

suitable one. For completing the missing limbs, the most promising one seems to be Poser 8, for other objects Leonar3Do and other 3D modelling tools are employed. The pediment will be reconstructed in ArchiCAD and the completed models will be set into this frame in order to test the feasibility and the aesthetic effects of each reconstruction. Our aim is to achieve a complete virtual reconstruction of the east facade of the building and to present a full documentation similar to the CD-ROM of SIBA (Lecce) on the metopes of temple C at Selinunte (ISBN 8883050398; cf. BERALDIN et al. 2009).¹⁵⁹

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Neutron Resonance Capture Analysis (NRCA), elemental compositions of bronze age objects

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Abstract: Neutron resonance capture analysis (NRCA) has been applied to determine the elemental compositions of three valuable, precious and very well preserved ancient bronze objects from the National Museum of Antiquities in Leiden (NL). For this study it was not allowed to use analytical methods, for which samples should be taken from objects. For this reason they were studied by NRCA using epithermal neutron beams from the pulsed neutron source of the GELINA facility of the EC-JRC-IRMM in Geel (Belgium). Neutrons can penetrate thick layers of materials, and therefore this method provides bulk compositions. NRCA is a fully non-destructive method. Since thermal neutrons are removed from the beam, the activation of the objects is low already directly after the measurement and fully negligible after a short waiting period. This research is part of the European ANCIENT CHARM project.

Keywords: neutron capture; resonances; elemental composition; non-destructive analysis; Bronze Age objects

Introduction

The underlying physical phenomenon for neutron resonance-capture analysis (NRCA) is that absorption (capture) of neutrons by nuclei as a function of neutron energy shows sharp peaks (resonances). These resonances are specific for nuclear isotopes and therefore suitable to identify and to quantify elements in materials and objects. That is, an element can be recognized on the basis of the energies of one or more of its neutron resonances. The areas of resonance peaks provide information about the amounts of elements. Capture can be observed by detecting the prompt emission of gamma rays, which are emitted during capture processes in most elements and with a total gamma radiation energy of the order of 5 to 8 MeV. The energy of a captured neutron can be determined from the time (t) the neutron needs to travel over the distance (L) between the neutron source and the object in which the neutron is captured. This information gives the velocity $V = L/t$ of the captured neutron and thus, in the non-relativistic, low-energy realm, the neutron energy is $E = \frac{1}{2}m(L/t)^2$, where m is the neutron mass. With a pulsed neutron source the time-of-flight t can be determined from the start pulse from this source and the stop pulse obtained from the detection of the prompt gamma-radiation. Since it is not necessary to have a good energy resolution for the gamma rays, one can use large scintillation detectors for this purpose. Consequently the efficiency for detecting capture

events is high. With a relatively simple detection system this efficiency can easily be something like 10 - 20% or even more.

Pulsed neutron sources can be realized with certain types of accelerators. The results described in this paper are obtained with the pulsed-neutron source of the GELINA facility of the EC-JRC Institute of Reference Materials and Measurements (IRMM) in Geel (B). Its basic unit is a 150-MV electron accelerator, which produces bursts of electrons as short as 1 nanosecond with a maximum repetition rate of 800 Hz. Stopping the accelerated electrons inside a target of heavy metal generates hard gamma radiation known as Bremsstrahlung. In the case of GELINA the target is a rotating disk of uranium. Bremsstrahlung in turn produces high-energy neutrons inside the uranium disk. A part of the neutrons escaping from this target enters two 4-cm thick containers located just above and below the disk and filled with water. These neutrons are slowed down and in this way a neutron spectrum is obtained from thermal energy up into the MeV region. In the epithermal range the energy of the neutrons is roughly inversely proportional with energy. For the reported experiments the useful range of neutron energies is from about 1 to 5000 eV.

In a paper by Mondelaers and Schillebeeckx (2006) more details about this pulsed-neutron source and time-of-flight (TOF) systems at GELINA are given. A typical resonance spectrum obtained with this facility is shown in figure 1.

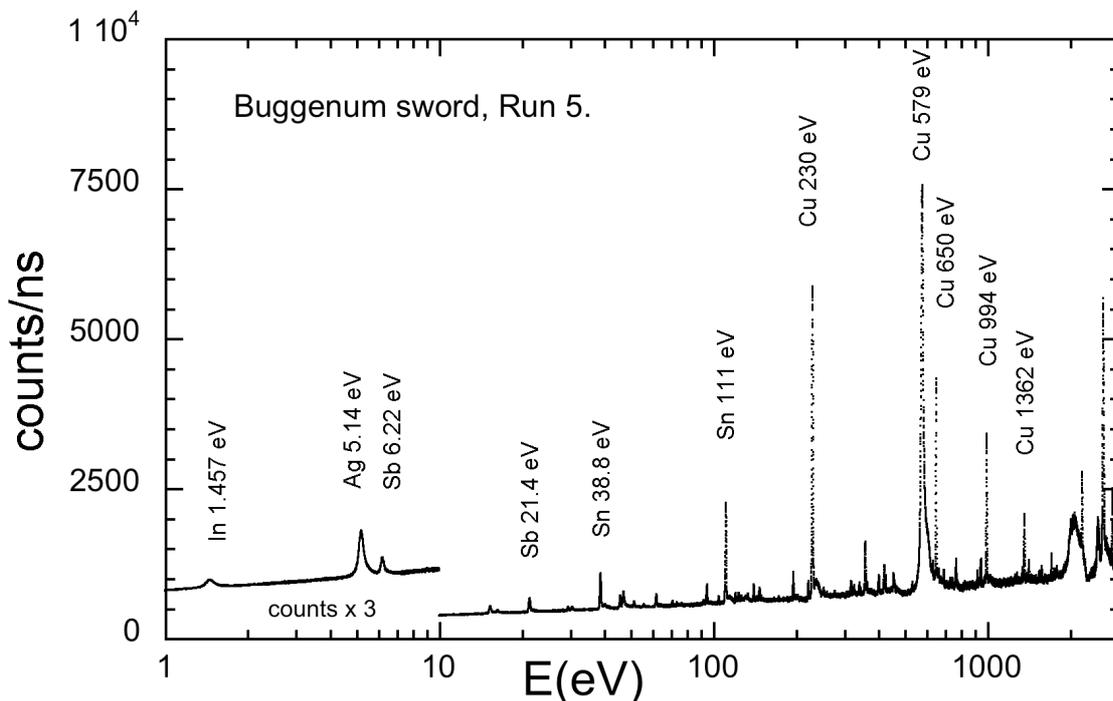


Fig. 1 – A typical resonance spectrum obtained with the Buggenum sword from the National Museum of Antiquities (NMA) in Leiden (NL). Some resonances, important for NRCA, are indicated with their element and energy.

In this paper the results of some NRCA measurements are presented as examples about what can be obtained concerning elemental compositions of objects. These measurements have been carried out with three bronze objects on loan from the National Museum of Antiquities (NMA) in Leiden (the Netherlands). All three objects are precious and very well conserved objects. NMA showed great interest in the determination

of the compositions of these artifacts, however only non-destructive analytical methods were acceptable for these objects. Therefore NRCA has been applied to these objects.

Some details of NRCA

There are basically two ways to analyze NRC spectra; that is:

- A) Absolute method to determine the amounts of elements based on knowledge of resonance parameters, detection efficiencies for capture events, neutron flux data, and size and shape of the object.
- B) Relative method to determine the ratio of elements based on the comparison with calibration samples. In this method it is not necessary to know resonance parameters, detection efficiencies and the absolute flux. It requires calibration measurements carried out under the same conditions as the measurements with the artifacts.

Most of our analyses of ancient artifacts are carried out with the relative method, in our case comparing elements of the bronze objects to copper as the main component. Since it is based on the ratio of areas of two resonances, one from copper and the other from another element, for the object as well as for a calibration sample with known composition, one is in fact dealing with a double ratio method. In this way problems due to irregular shapes of objects and to the often insufficiently known properties of resonances are circumvented. The weight ratios of elements with respect to copper can be converted into absolute values (e.g. in weight %) if it can reasonably be assumed that all elements are known, maybe with the exceptions of a few weak components. Actually this is a general problem also for other methods, which are not able to determine all elements of an object.

The basic information for determining elemental amounts are the numbers of captures (counts) in the chosen resonances. The number of counts in a resonance peak is obtained as a sum of the channel contents of the peak after background subtraction. The latter requires some care.

Apart from capture there is always scattering, which can be followed by capture inside the object. These scattering-followed-by-capture (SC) events add to the TOF spectrum. Since neutrons lose energy in the scattering process each resonance peak may show a broad structure at its high-energy side. Part of this SC structure is underneath the capture peak. This must be subtracted from the spectrum to get the correct number of events of a capture peak. This can be done for instance by a parametric fitting procedure. For very low energy resonances a larger part of the SC structure is underneath the capture peak as compared to higher energy resonances.

Another important correction concerns the fact that the neutron flux diminishes during penetration of the object due to capture and scattering. Notably this occurs at resonance energies, which therefore reduces the number of capture events in resonance peaks. This is known as the resonance self-shielding effect. It is a factor to be taken into account in the analysis. It can be calculated in most cases sufficiently accurately on the basis of the total Doppler-broadened neutron resonance cross section.

For several elements it is possible to choose more than one resonance for the analysis. For copper suitable resonances are at the 230, 650, 994 and 1362 eV and for tin resonances at 38.8, 45.75 and 111 eV can be used; see figure 1. That means twelve pairs of Cu- and Sn-resonances can be used to calculate the Sn/Cu weight ratio. If one is dealing with a thin object (in which therefore self-shielding does not play a role) of a tin-

bronze the twelve pairs of resonances should give the same weight ratio. However, for thick artifacts the count rates in the resonance peaks are diminished by self-shielding factors, and since these resonances have different strengths count-rates are affected in different ways. Without correcting for self-shielding the experimental weight ratios are therefore different. Hence correction for self-shielding can be important, and since self-shielding depends on the thickness, an effective thickness can be found at which the corrected weight ratios for the twelve pairs of resonances are equal. This provides a simultaneous determination of the Sn/Cu weight ratio and an effective thickness (areal weight in g/cm^2). More details of this and other aspects of NRCA can be found in Postma et al (2004), Schut et al (2008), and Postma and Schillebeeckx (2009).

The artifacts

The three artifacts on loan from the National Museum of Antiquities in Leiden (NL) are:

- a) the Buggenum sword, which was found during the dredging of a lateral canal of the river Meuse in a village near Roermond (NL) It is dated from about 1300 – 1100 BC,
- b) The Jutphaas sword, which was accidentally found near the river Rhine. It is one of five very similar swords without a hilt. It is a thin, skillfully crafted blade without provisions for attaching a hilt, a non-utilitarian, ceremonial object dated from 1500 – 1400 BC.
- c) The double axe from Escharen, a small village on the Raam a tributary of the Meuse and near Grave (NL). It is dated 2100 – 1800 BC.

The main results of NRCA measurements obtained with these artifacts will be reported with some discussions of the objects.

The Buggenum sword

All-metal swords with very similar decorations as the Buggenum sword are known from upper-Danube and its tributaries north of the Alps. Therefore the Buggenum sword is thought to be from this region and since it was found in the Netherlands, it must have traveled a long distance. This sword is considered to be a ceremonial object and it is dated to the Hallstatt A1 Middle Bronze Age period (13th -11th c.BC). (Butler, Fontijn 2007) It does not show any sign that it has been used as a weapon. The blade and the hilt are of different casts of tin-bronze with 12% respectively 13% tin. They contain the minor elements Sb, As, Ag and In with diminishing amounts in this order, constant over the blade, however, with slightly different values for antimony and arsenic in the hilt. More details of the NRCA measurements and results of the Buggenum sword are given by Postma et al (2009) together with results from neutron diffraction at ISIS (UK). From the latter results it is argued that the Buggenum sword has actually been made as a functional weapon.

The Jutphaas sword

This artifact is one of a group of five very similar swords with sizes from 42 to 70 cm. The Jutphaas sword is the shortest one of them. They are found in the United Kingdom, France and the Netherlands and are known as the Plougrescant-Ommerschans type of swords. None of them are equipped with a hilt or have remains indicating how hilts could have been fastened to these swords. They are clearly useless as weapons. It is assumed that they are meant to be ceremonial or impressive objects for their owners. (Buttler, Safratij, 1970/1971), (Fontijn 2001) They are considered to be from the Middle Bronze Age (1500 – 1400 BC).

Two NRCA-measurements have been carried out with the Jutphaas sword; a long run at the top and a shorter one at the tip. It is shown to be a 13 wt% tin-bronze with the minor elements Sb, As, Ag, Zn, Co, In, Fe and Ni; the latter two showed up only in the longer measurement at the top section. Lead could not be detected in both runs with an upper limit of about 2 wt%. The compositions deduced from the two runs of the Jutphaas sword are very similar and in addition also similar to the compositions measured for two other swords of this series, namely the Beaune and Oxborough swords, and similar to the composition of a related, but not identical sword found in Kimberley. (Needham 1990) The Kimberley sword has a slightly different shape and is not considered to belong to the Plougrescant-Ommerschans type. Figure 2 shows the composition of the Jutphaas sword as a bar plot on a log-scale.

The Escharen double axe

This metal artifact is a strange object and certainly not useful as an axe. It is considered to be a Zabitsch type axe of which there exists only a very limited number. (Butler 1995/6, Fontijn 2002) It has a hole in the middle too narrow to be securely hafted. NRCA showed that it is a fairly pure copper object with a very small amount of tin and the minor elements Sb, As, Ag, Co and In. For zinc an upper limit is given. Figure 2 shows its composition as a bar plot on a log scale. The largest amount concerns arsenicum. This composition resembles closely the Singen composition. (Butler, 1995/6) The Escharen double axe is considered to be from the early Bronze Age (2100-1800 BC).

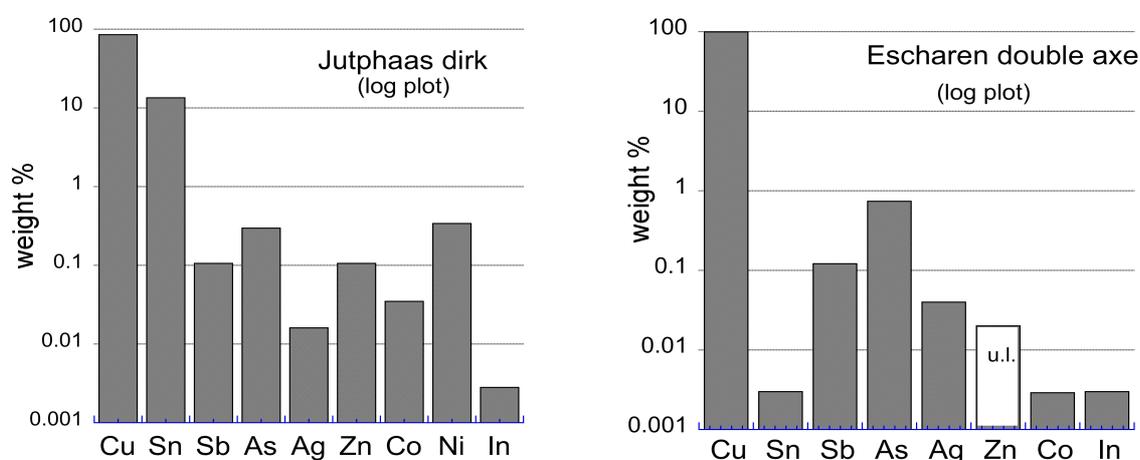


Fig. 2 – Bar plots on a log scale of the compositions of the Jutphaas sword and the Escharen double axe in weight %.

Activation by neutrons

Capture of neutrons may lead to activation of an object since part of the isotopes produced by capture can be unstable. In many cases the half-lives are short and the produced activation may already partly disappear during the NRCA runs, or otherwise during short waiting periods after the measurements at the GELINA facility. Some long-living isotopes can be produced but that has never been a problem at the GELINA facility due to the low neutron fluence and the removal of thermal neutrons by either a cadmium sheet of 1 mm thickness or a disk containing ^{10}B . This reduces activation by thermal neutron by a very large factor. Activation may still occur by resonance capture, but this leads at most to a very low activation at the GELINA

facility. As a consequence objects studied by NRCA can be returned to their owners after a short waiting period, normally less than one day.

Advantages and limitations

NRCA determines the composition of the bulk matter of an object. It is not necessary to do any preparation. Removal of the patina is not necessary since this is normally thin compared to the bulk, and thus it has little or no influence on the result. NRCA is a non-destructive method and can be applied to irregular and fragile objects. By removing thermal neutrons, which are not of interest to NRCA, from the beam reduces the activation to a very low level and activation is negligible after a short waiting time.

A disadvantage is that the NRCA method can only be carried out at a limited number of accelerators; in Europe at the GELINA facility of the EC-JCR Institute for Reference Materials and Measurements in Geel in Belgium and at the ISIS facility of the Rutherford-Appleton Laboratory in the UK.

The GELINA facility should therefore be used mainly for cases of expensive or rare objects. The ISIS facility with its much higher neutron flux could be an interesting future facility for NRCA measurements of large series of objects. Even very small objects can be measured within a short time as has been shown by test experiments in the ANCIENT CHARM collaboration; see the paper by Gorini (2009) presented during this conference.

Acknowledgement

The experiments reported in this paper have been carried out at IRMM in Geel (B) using the GELINA facility, which is very skillfully operated by the dedicated staff of Wim Mondelaers. Many thanks go to the National Museum of Antiquities in Leiden (NL) for the loan of the objects mentioned in this paper. This research has been carried out under the EU FP6 Ancient Charm project, funded by the European Commission under the contract No. 15311.

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The Rise and Fall of Avitus

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Abstract: This article describes creating of a system for digital data processing, designed especially for archaeology. It includes suggestions how to systemize and process data from points to larger groups. Every part of the application is described in detail along with the specific problems we encountered during development. It can serve as a starting point for anyone with some basic programming skills to develop an application and shows how complex it can grow with sufficient support and enthusiasm.

Keywords: digital data processing, data storage, data analysis, Autocad, archaeology

First, the sad news: due to the current situation in Slovenia, the application and system Avitus, although still actively used, will not be developed any further. It would require political will beyond flowery phrases about supporting innovation and a wider consensus for its use. Probably the situation around Europe and the world is not that much different. Therefore this article will discuss the process of creating a system for collecting, archiving and interpretation of data in hope it will benefit anybody who might pursue the same goals. As a reader will find out, designing such system is cost efficient, time saving and increases capabilities of researchers on the site and after the excavations.

Why was such project necessary in the first place? At the time of first development the use of computers and digitalization was slowly entering and replacing the classical ways of dealing with data at excavations. Digital data is easier to backup, copy and share and is more reliable and faster to obtain. We can collect more information in shorter amount of time, if done properly. But there is a certain lack of IT knowledge amongst the archaeological community, especially when dealing with more complex ways of data interpretation. Vice versa, the IT experts lack archaeological education. Most software available was a derivate of architectural software, modified only in smallest measures to fit to the field work.

So the first goal was to create software designed by archaeologists and only developed by IT experts. I, as the latter, had to acquire the necessary knowledge and not the other way around. Time limits, specialized equipment, field work, terminology and special procedures were all taken into account at the very beginning. The second goal was the possibility that the archaeologists themselves use the system independently, which required a friendly and comprehensible user interface with the shortest learning curve possible. Next, we wanted to create a single-file central platform, from which we could access all the information collected. This included support for database, photos, scanned drawings, 3D scans, etc. We decided upon an Autocad DWG file, which enabled strong programmability and inter-connectivity with other applications. Avitus supported independent input from many co-workers, even at the same time.

The next problem was designing a system that fits various archaeological projects, from burial sites to urban archaeology, indoors excavations and large outdoor sites. It should easily handle large amounts of data, even on excavations with over 10.000 finds, stratigraphic units, drawings, etc. Every entity, collected and entered into the system should be easily retrieved by various criteria (such as its type, age, location, etc.)

and shown/hidden accordingly. Some sort of systemization was imperative, also to be able to view and connect different excavations regardless of the researcher. This was the second reason to choose already established file formats, such as Autocad DWG/DXF and Access DVB. Content can be easily shared and used even without Avitus application. We also included support for exporting data in other standard formats (TIFF, PDF, XLS, JPEG, TXT,...).

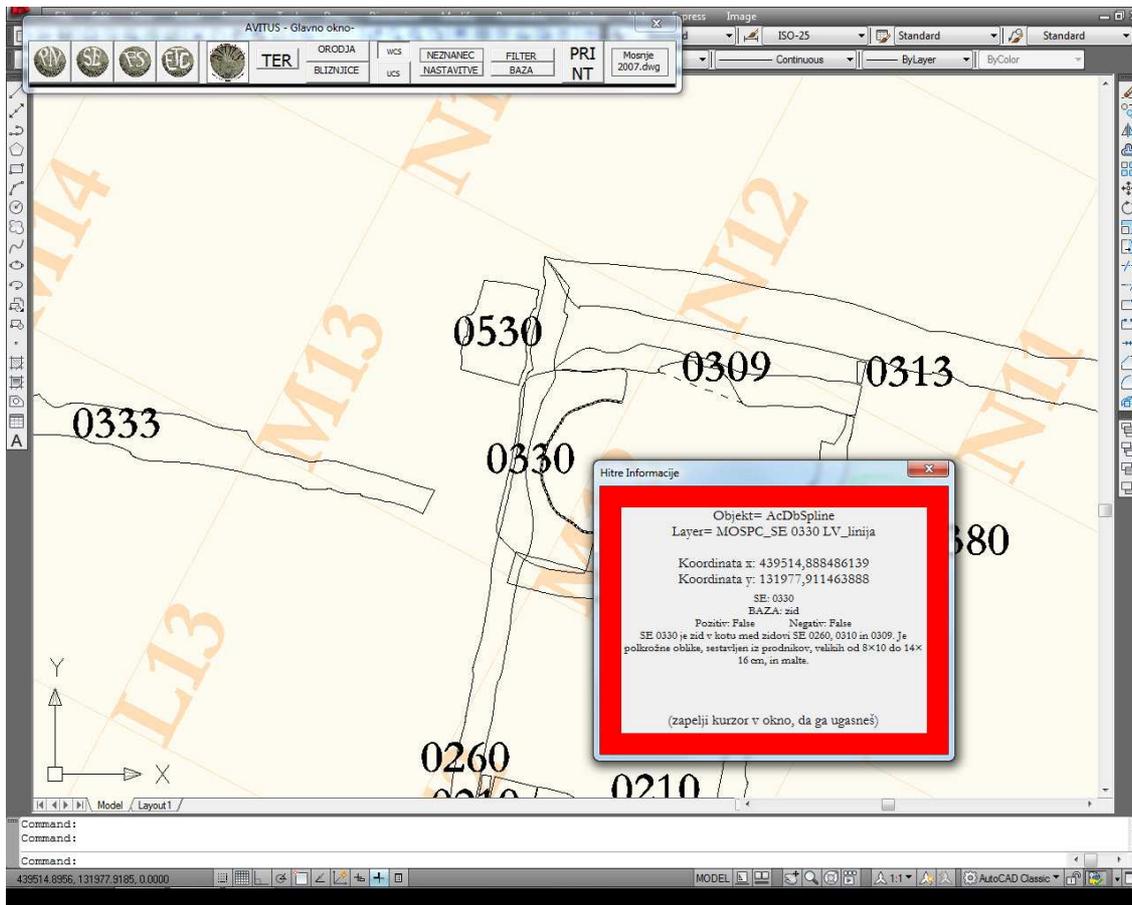


Fig. 1 – Avitus toolbar takes little space when minimized. Here is also shown the example of quick info, obtained by right-clicking on any object.

But with all the mentioned situations and deficiencies, the archaeological community in Slovenia has many other problems. There is still a struggle with putting heritage and important studies before profit. Dependent on political will, any development or setting of standards is always subject to whims of people in charge. Even though the system was developed for virtually no cost, financed through excavations, there was no broader will to pursue it further. A new law shifted the excavations to private companies. In such situation, the goals to unify standards at least on a market as small as Slovenia, to provide a common, cost free, open platform are even more critical. But, ironically, this turned against us. For the reasons stated, the programming code was left open, so that people could modify language, categories and such. A private company, for which I also worked and gave them basic knowledge of programming, used the fact that no protection was applied, for intellectual theft to create their own software, applying enough differences to eliminate compatibility. This is more than anything sad. There are still no minimal, state-set standards for excavation and data processing. It is up to the companies that do the research and their determination to

further the quality. Apart from a few bright cases, it is cheaper to not adapt if the regulations do not force you to. But since they want to keep an edge over competition, there is no desire to come together and unify at least the basic nomenclature, even though they all work in similar ways. As far as excavations from the institute go, the standards were at times mandatory, at times welcome and at times not wanted at all, since they initially raised costs. This was the main reason the project was discontinued.

The other reason is technical. VBA, a standard tool for programming and customization of Windows applications, including Autocad and Access, will no longer be supported in the future. There are some differences in programming in 32bit and 64bit environment. So the same code from the 32bit system on 64bit system sometimes works flawlessly, sometimes it slows the system down and other times it does not work at all. In the next years all applications such as Avitus should migrate to .NET programming platform or C++ language. A tool named VSTA will substitute VBA. Although the code would have to be rewritten, it should not affect the Avitus (or any other similar) system itself. Everything written here does not change the basic approach to the data collection. It should serve only as a reminder and possibly a guide for other developers. The system itself is not new: similar approaches have been used world-wide. But it has been modified for computers and digital data. Avitus uses structuring from smaller to larger units, starting with a point and ending in groups of different objects, bound together by a common denominator. The reason for this is that we often look only for a certain point and its properties, but other times we are interested in larger, more complex groups, that can consist of points, lines or photos respectively. So a basic unit is a point, defined by the XYZ coordinates and a unique codename. We collect these points mainly with total station. Codenames can be short, as long as they are unique. Our system uses the following coding: First part is the type of the point or entity it represents (these types are discussed later in the article). It can be a find, sample, stratigraphic unit, border, etc. We use two or three letters to assign this information. The second part is the number of entity the point represents. Usually a four digit number is enough. The third part is the specific number of the point within this entity, as an entity can consist of many points. This number usually has three digits. So the first point of a certain find, named NA 0001, is named NA 0001 001. Total station can count the next collected point automatically.

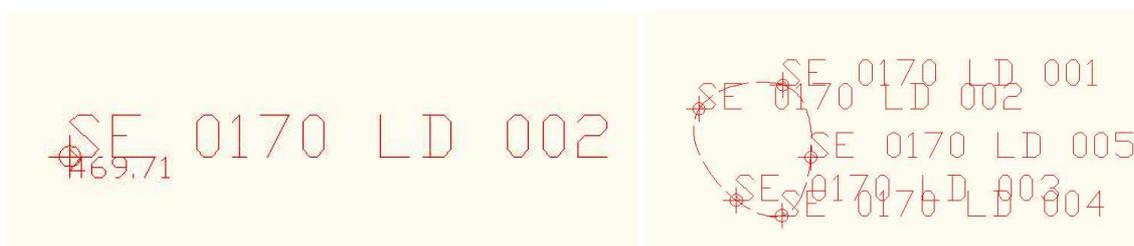


Fig. 2 – A point with its unique name and height.

A group of points all part of the same stratigraphic unit.

Avitus automatically processes each point based on this information alone. Because it can recognize the type of a point, it can put it on an according layer (creating it if necessary), applies a certain color, thickness, etc. Point that belong to the same codename group (i.e. the same stratigraphic unit), can be processed further, manually or automatically. They can be connected with lines (with specific linetypes, colors, widths,...), divided into new categories (such as stratigraphic unit top (SE *n* LV), bottom (SE *n* LD), contour lines (SE *n* IZ), cross-sections (SE *n* PP), details ((SE *n* DE)), heights ((SE *n* VI)),...), and treated like a

singular entity. This leaves us with many layers with detailed, easy to understand names (i.e. MOSPC_SE 0344_IZ_linija), that are created automatically by Avitus, with only one or two clicks.

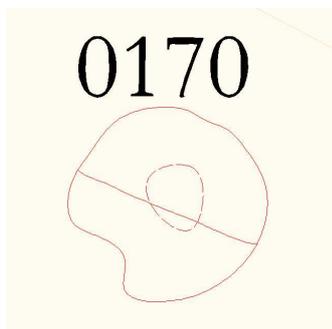


Fig. 3 – The same stratigraphic unit with only top, bottom, cross-section and label displayed.

The other information about entities is input in the Access database, which is at all times connected with Autocad, although it can also act as independent application. Based on the data here, we can create new groups, to form larger, logical systems. We can group certain walls into a building, or we can group finds with specific dating span into one group. While we only need to define a point correctly (in a semi-automatic process), the system can automatically recognize it individually, as a larger entity or as a pre-defined group. Process of input of points into Autocad is fast, simple and intuitive. User can verify the automated process step-by-step as the points are grouped, connected, assigned to layers and given labels. All the other information is stored in the database, which is completely flexible and enables easy addition/deletion of categories and types. More time can be spent at collecting important information, which in return improves analyzing capabilities of Avitus.

This leaves us with creating a system for types of points. Even though it is open to change, it follows some basic rules. We divided all entities into four different levels. Each level is processed differently through Avitus. The basic type is punctual. It applies to entities, that are represented with only a point: these are finds (most of the times), samples, anchor points, etc. The next type is planar. It represents logical group of points, which is usually connected with lines (normally the points are hidden after lines are created) and can have many sub-categories. Such entities are the stratigraphic units, borders of excavation, structures, etc. The third type is raster. It includes inserted photos, land registers or scanned drawings along with the points, with which they are referenced. They have optional interpretation or digitalization layers. The fourth type includes everything else: from various grids to notes and analyses. We designed a specialized set of tools for each type of entities.



Fig. 4 – Main window of Avitus application with links to other modules, settings and a special row with tools and shortcuts.

A user can process about 1000 collected points per hour. Each entity is automatically backed up as a separate file. The main file, containing all the points also automatically creates a backup at chosen intervals. This leaves us with a single file with huge amount of points and many layers, along with a database and additional photos and scans. The information is safely stored, even if we share it with computers without Avitus application. But here usage of Avitus only begins.

On large excavations, all the points in a single file can present a problem. It is very hard to find what we are looking for, so we use layers to hide what we are not interested in at the moment. As mentioned before, Avitus creates these layers automatically and it can also manage them very efficiently. Each type of entity (punctual, planar, raster, other) has its own stand-alone module for revision and modification of data. Main part of each module is a list. We can choose a type of entity and Avitus, thanks to unique layer names structure, filters through all the layers and finds i.e. all the stratigraphic units. It lists only numbers. Because a single stratigraphic unit can have more than 20 sub-categories (top, bottom, contours, heights, label...), Avitus automatically displays all the existing sub-categories for a chosen stratigraphic unit in a form of checkboxes, where we can show/hide any layer we want. We can also create a preset of a combination of shown/hidden layers, which we apply with one click. So the information we are not interested in remains hidden.

After we select a certain entity, Avitus calculates and displays information about it: its coordinates, average height and area/volume for more complex entities. It can calculate between various coordinate systems for us. It displays any comments about an entity, whether it is a part of larger group(s), etc. We can zoom to it with a slider or have Avitus zoom on an entity automatically, when it is selected. Alternatively, we can have the outline of the entity highlighted or flashing in red a few times to locate it without zooming in. We can also change display properties for each entity separately (or for groups) from linetype, color, thickness, justification, etc. We can further correct any entity or its location. We can isolate it in 3D view (or viewed in combination with other entities), error-check it, search for its photo within folders, or the location within the grid of quadrants. There are many specialized tools for specific entities, i.e. we can search for finds within a stratigraphic unit.

The next part of each module is the database connectivity. Each type of entities has one or more corresponding tables within the database. While in Autocad, Avitus automatically connects to these tables and provides information about entity as we select it. Access does not even need to be installed on your system. Here we can review and change information in the database. We can also simply select any object in Autocad and it can be automatically selected in the Avitus module.

Implemented inside the Avitus are powerful filters for database, that can employ up to four criteria at the same time, using logical (and/or/not) operands. We can i.e. search for all the fibulae where material is silver or material is bronze and that are dated before 300 A.D. Results are displayed on separate list. These new lists can be further cross-checked and combined with other existing lists, other entities, separated into parts and saved for later use. They can be statistically or spatially analyzed.

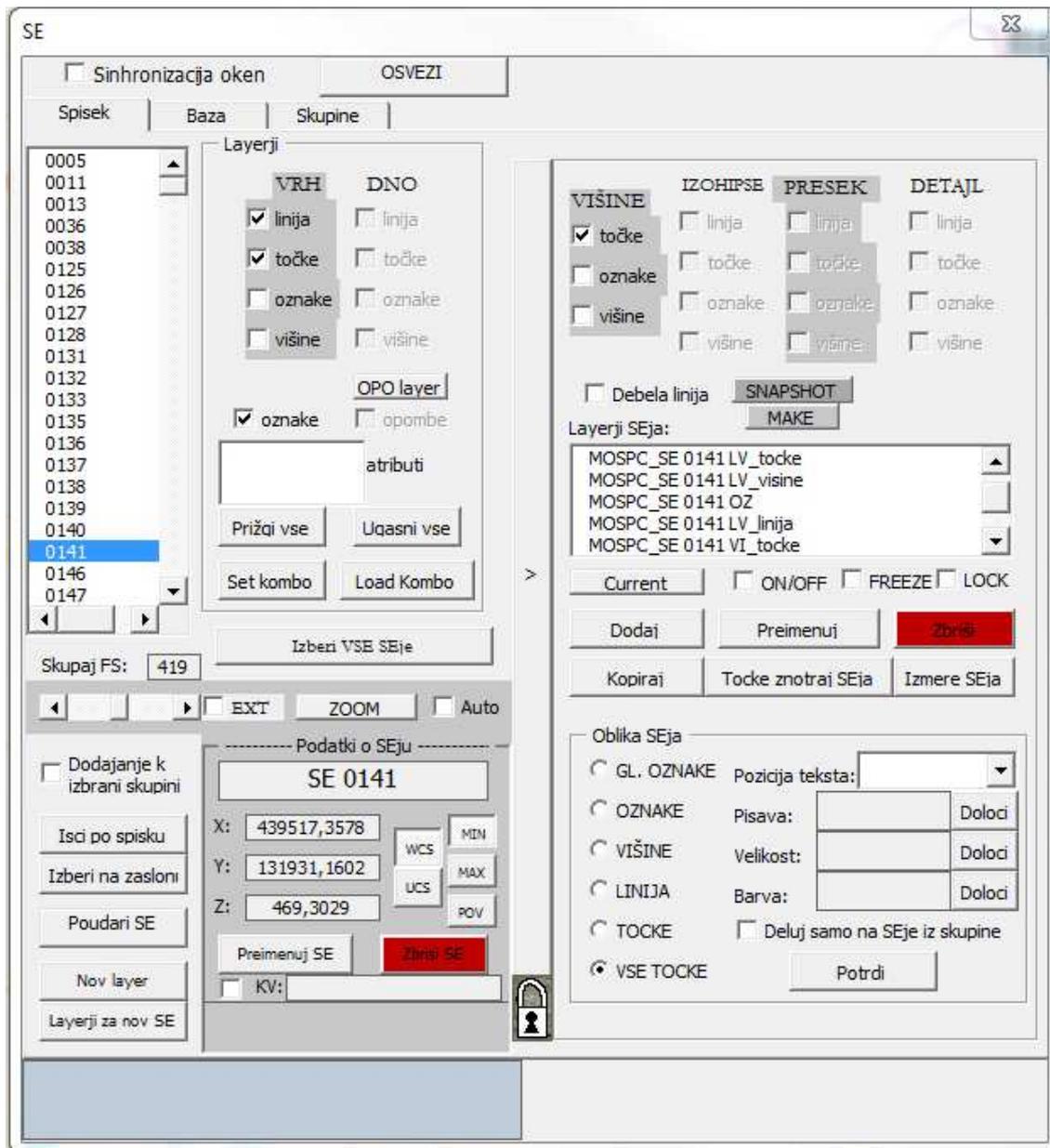


Fig. 5 – Module for planar entities (i.e. stratigraphic units). On the left is a list of all entities of the type found. The right panel with advanced tools can be hidden or locked.

We can also create these lists from scratch by typing in the numbers of entities, or selecting them in Autocad. We can create multiple lists at the same time; i.e. Avitus enables us to sort all finds according to material, thus creating separate lists for bronze, iron, clay,... finds. We can combine these lists to include metal finds or further separate them by date. Possibilities are limitless. After we create and save these groups, we can show them in our Autocad environment or in a separate file. There are many built-in ways to present them, from simple symbols (color-varied circles, crosses, etc.), to more complex, built-in symbols, which represent jewelry, armor, weights, vases, bones, nails,... We can add textual labels and automatically create appropriate legend. Everything can be exported as a PDF, XLS or other supported formats.

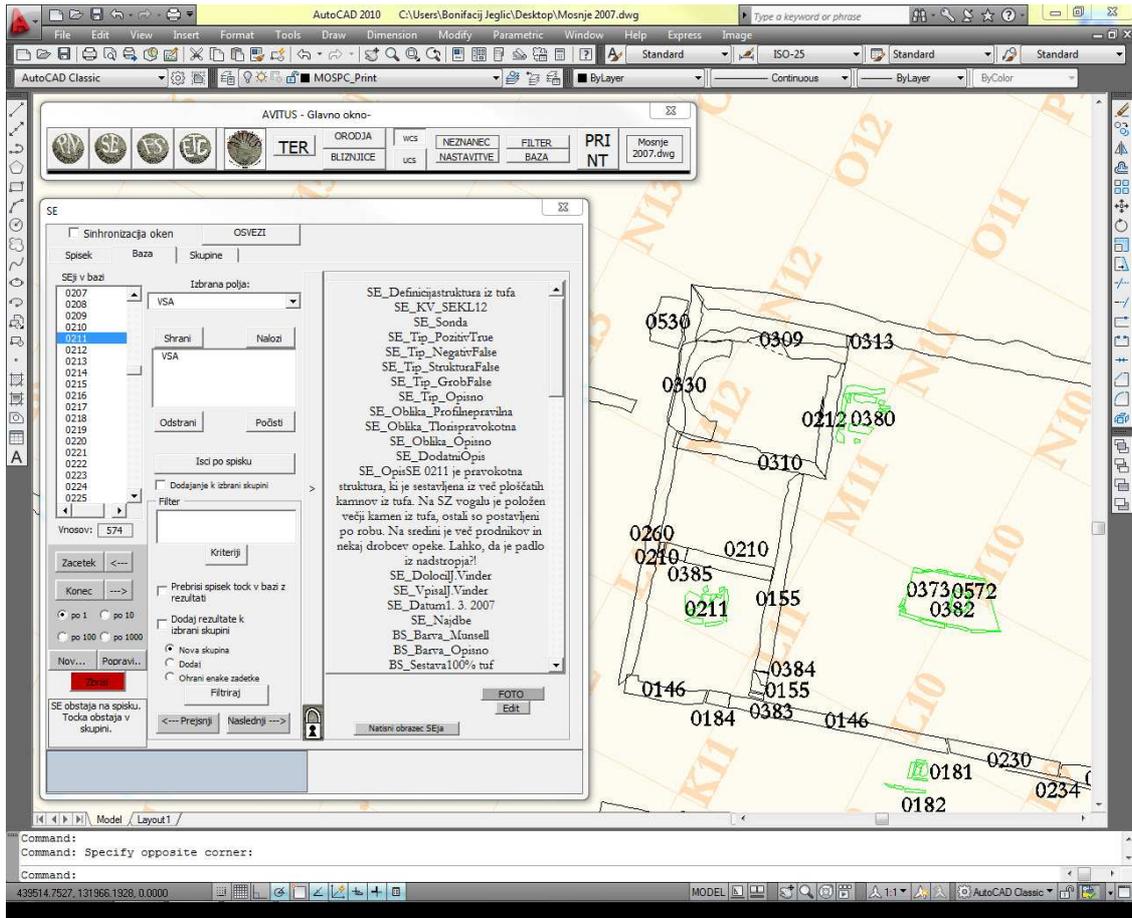


Fig. 6 – Database module for selective display.

The other part of Avitus is designed to improve functionality. Everything can be set according to user- the whole folder structure can be redefined. Inexperienced users can have fewer commands available. There is a function, which allows users to only view the data, but prevents them from modifying it. We also designed a set of shortcuts and tools, out of which, twelve can be placed directly on the interface for quick use. These include tools for automatic connection of points, layer generation, computations and measurements, inserting geo-referenced notes, quick manipulation of shown/hidden layers, exporting, coordinate system creation, etc. Some tools are just shorter versions of Autocad commands, that shorten the time, since we do not have to browse the menus.

We added other tools for publishing, printing to scale on different paper formats and layout generators. There is also frame and label editor with automatic north pointer and preview. We also shortened the processes for photogrammetry and added other tools for image manipulations. A part of Avitus is also Harris matrix editor, where we define our own set of correlations. The program can check all the data for impossible stratigraphic correlations, even if the certain layers are not directly connected.

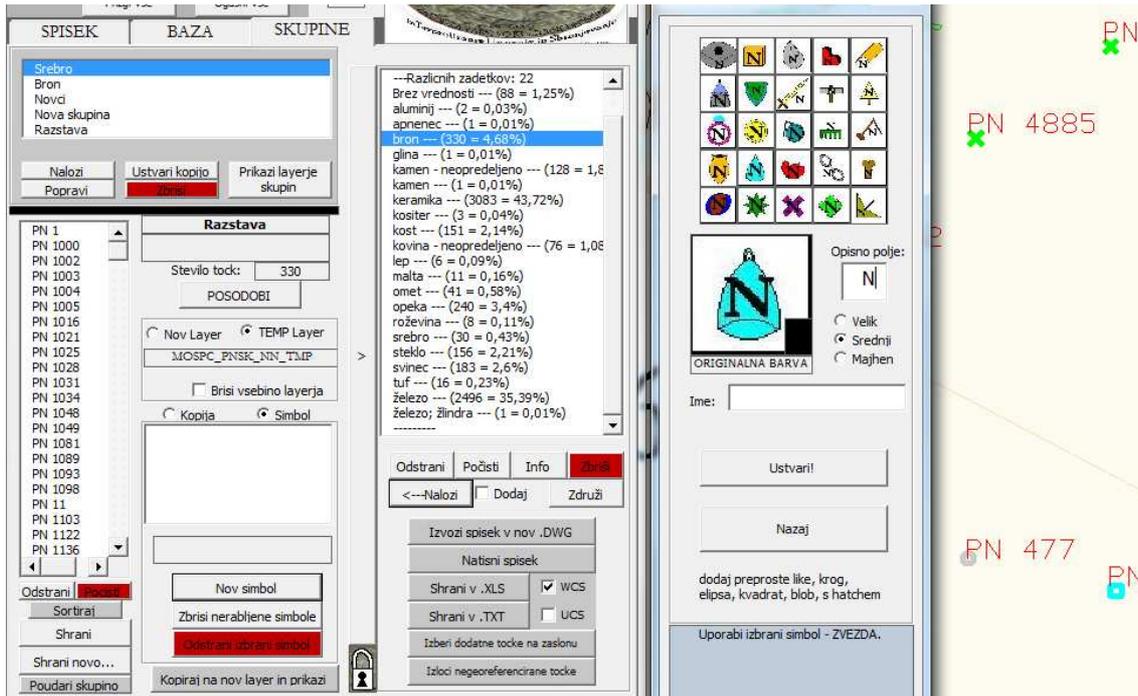


Fig. 7 – An example of working with lists and symbols that represent different groups.

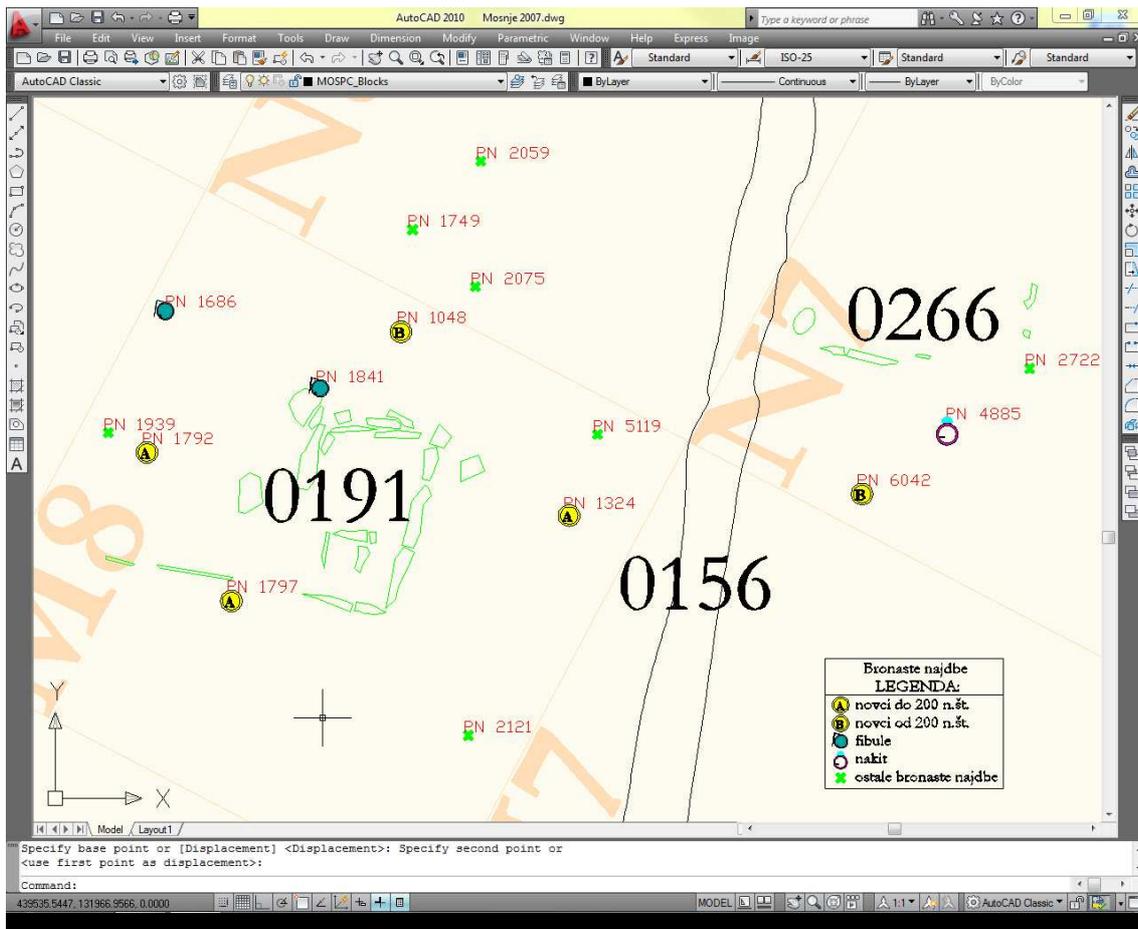


Fig. 8 – The result of different representation of finds, which can be achieved with a few clicks.

The database was designed primarily as part of Avitus, but can also function on its own. It is organized with tables, which we fill through intelligent forms, that simultaneously perform error-checking. Database has its own user settings and log. We can easily create complex queries and reports. We have a possibility of many independent working instances of the same database, which are then combined together to contain all the information.

Fig. 9 – Main database module (left) with example of a form for a table (right).

There are many more ideas and new technologies we could pursue. We could implement large point clouds from 3D scans more actively, use surfaces instead of lines to represent stratigraphic units, create automatic cross-sections and try to digitize as many older projects as possible. Total stations are getting more accurate, easy to handle, automated and wireless. There is ongoing debate about putting content online. There is much to do in the field of unifying procedures and nomenclature world-wide, of putting the knowledge in the same pool, quickly accessible by many scientists throughout the world. In any case, much work is still to be done, and we hope Avitus will be a small part of the heritage of digital data processing. For any further information or help regarding the topic in question, please feel free to send us an e-mail to the mentioned addresses.

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Article is mostly original. Still, some of the terminology and data are derived from the following sources:

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P. Novaković, D. Grosman, R. Masaryk, M. Novšak: Review of the current status and suggested minimal standards for field archaeological documentation (study). Ljubljana, 2007.

R. Klasinc, M. Ravnik: Tica Sistem Standards 400+ White edition: Excavations manual. Ljubljana, 2002.

Some of the projects are presented on the webpage of Institute for the protection of cultural heritage at <http://www.zvkds.si/>

Web Based Applications for the Promotion and Dissemination of Cultural Heritage Sites and Monuments

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Abstract: In the last few years, the Laboratory of Geophysical – Satellite Remote Sensing and Archaeo-environment of the Institute for Mediterranean Studies – FORTH has undertaken the compilation of a number of Web based applications (more than 45 Databases and 40 WEB_GIS applications) for the promotion and dissemination of recorded information regarding cultural heritage sites and monuments. The particular projects integrate a number of modules that make the corresponding web sites attractive not only to the tourists and the wider public, but also to researchers and scholars who are using them for educational and research purposes.

The web applications are accompanied by archaeological data bases, ethnographic data, dynamic GIS maps (containing information on both archaeological sites and natural resources), photo and video galleries, visualization panoramas and 3D reconstruction models, deviating considerably from the usual tourist or other static archaeological portals, since they can provide contextual information, geographical data and multimedia that can be used from a wide variety of users. The registered sites and monuments are not limited to the most significant places, but they include sites from both excavations and surveys, monuments that are either restored or even badly conserved and a number of information that can be used for the further study of the monuments. Emphasis has been given to the recording of the sites and not to the details of the monuments they contain, in an effort to capture the geographic distribution of sites and the way of perception of space in the past. Video interviews from specialists dealing with interdisciplinary research in the domain of archaeology in Crete provide their own perspectives regarding the theoretical and practical issues of their research. Furthermore, tourists are capable of arranging their own itinerary to visit sites of their own interest. The data can be used not only for cultural monuments' information dissemination purposes, but in many cases they can be also used for the better planning of restoration works and large scale construction plans. The above technologies suggest a norm that can be used to enhance the cultural domain portals.

Keywords: Web Applications, Cultural Heritage, GIS, 3D, databases, CRM, Atlases, Risk Assessment.

Introduction

The interest concerning the cultural WEB applications is related to:

- The presentation and dissemination of records regarding monuments and archaeological sites
- The diffusion of the archaeological information in relation to the cultural or natural environment
- The geographic distribution in space – archaeological atlases
- The communication of the results of surveys and excavations

- The promotion of the results of more innovative techniques through technological means (e.g. GIS, remote sensing, laser scanning, 3D modelling, spatial analysis, a.o.)
- The creation of alternative means for education and training
- The tourism promotion for touring and proposals for tourist itineraries

The Laboratory of Geophysical-Satellite Remote Sensing & Archaeo-environment has developed a number of such applications by fusing the above interests, targeting to different audience (specialized researchers or wider public) and employing a wide range of technologies such as GIS, 3D modeling, panoramic views, satellite remote sensing and multimedia databases (SARRIS 2005, PAPADOPOULOS et al. 2009). As such, the material that is contained in the cultural WEB applications satisfies the qualitative standards of the context and at the same time constitutes an attractive way of accessing the cultural information.

This paper demonstrates such kind of case studies and explores the way of implementation and dissemination of the particular information. Examples are drawn from projects such as *Digital Crete: Cultural Mediterranean Itineraries*, *Byherinet: Byzantine Heritage Network*, *Egeria: Mediterranean medieval places of pilgrimage network of the documentation, preservation and enhancement of monuments in the Euro-Mediterranean area*, *Emarket – path E4 for the prefecture of Rethymno, a.o.*

Digital Maps and Atlases

The cultural, archaeological and architectural heritage referred to the Byzantine world is one of the most interesting aspects of identity for countries which face the east side of the Mediterranean Basin. The project *Byzantine Heritage Network: Rehabilitation, Highlighting and Management in the Eastern Mediterranean Basin (BYHERINET)* was carried out under the auspices of the INTERREG IIIB/ARCHIMED program and investigated tools that aimed towards the homogeneous registration and management of Byzantine cultural heritage and the creation of on-line and off-line platforms for the enjoyment of monuments and sites characterized by difficult conditions of accessibility, through tools and systems of the Information Society. The project's consortium consisted of the Basilicata Region, IBAM-CNR, the Lecce Province, the Prefecture of Rethymno, the University of Athens and the University of Cyprus.

The Lab of IMS-FORTH through its collaboration with the Prefecture of Rethymno undertook the responsibility of the GPS mapping of the Byzantine and Venetian sites of Rethymno region. More than 250 Byzantine sites and monuments were topographically registered to the digital archive maps of the Lab. An archaeological database was designed for the goals of the project constituting an electronic inventory for recording the archaeological and monumental sites together with their corresponding information, along with data concerning their state of preservation and restoration. The particular database and the GIS application that offers information concerning the spatial distribution of the sites are available through the WEB (<http://byherinet.ims.forth.gr>). Finally, a sample of 3D models of the church of Zoodochos Pigi at Prinós were made available through different navigation platforms (e.g. VRML or ImmerVision pure player) for the interior (using a 360 degrees panorama capture) and exterior (using 3D modelling techniques) of the church (Fig. 1).

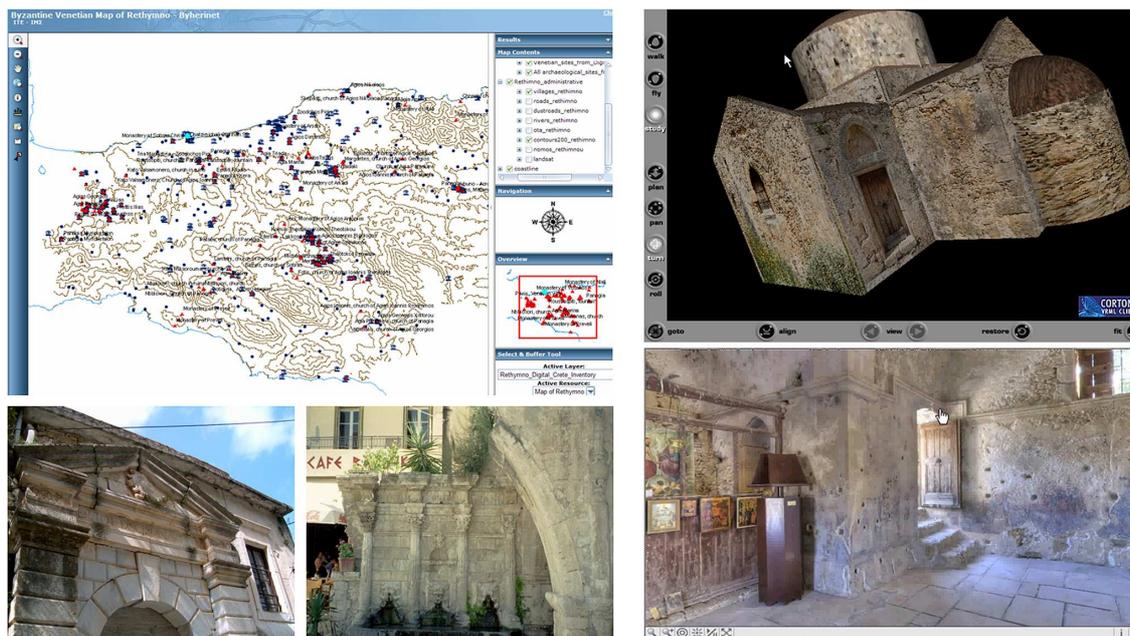


Fig. 1 – The WEB_GIS platform which is used for the dissemination of the records regarding Byzantine monuments of Rethymno Prefecture. Each of the site in the map is connected to the database which is accompanied by photographic material (left). The 3D touring of the Zoodochos Pigi church is also available through 2 different navigation platforms (right).

Of similar aspect but of a much broader sense was the project *Digital Crete: Mediterranean Cultural Itineraries*, which was implemented under the framework of the Greek Operational Program “Information Society”, which follows up the “eEurope” initiative of the European Union and which was funded by the 3rd European Community Support Framework (SARRIS et al. 2008). *Digital Crete* aimed towards the creation of an integrated cultural information node, consisting of digitized documentation and information regarding the cultural heritage of the island of Crete, from prehistory to the modern periods. *Digital Crete* incorporated diverse inventory modules, such as The Digital Archaeological Atlas of Crete, through the use of satellite remote sensing and Geographical Information Systems technology, a database on the Western Art of the island of Crete during the Venetian period, a database on EIGreko (Dominikos Theotokopoulos) and his works, a database on Ottoman Crete, including information related to the habitation and settlement patterns and existing monuments, a database on the history of Crete in the 20th century and an inventory of thousands of musical/cultural routes that include traditional music and sounds of Crete, video-recordings, poetic text passages, a.o.

The final results of the project included the creation of a Digital Documentation and Management Inventory Unit, which was established as a center for scientific research and educational activities, and an interactive WEB portal which is used for the wide dissemination of the cultural information of Crete accepting more than 20,000 visitors per year. Of extreme interest is the *Digital Archaeological Atlas of Crete*, the geographic database of which includes the coordinates of the major archaeological sites (prehistory to modern historical times), information regarding their environmental context, the way of their discovery, their conservation and protection status, together with a catalogue of the most significant architectural monuments of them. The collection of the archaeological data (more than 5,500 toponyms) was carried out through published data in scientific journals, series and monographs and it has drawn the attention of international researchers who not only use the particular platform for their research or teaching needs, but also contribute to it through their own datasets. Each toponym (site) contains a summary of the usage of the landscape in various time

frames, the researchers who were involved in their investigation and study, the types of scientific approaches used and the corresponding periods of study. The cartographic layers that accompany the Digital Archaeological Map of Crete have been categorized into different thematic groups. Background layers consist of satellite images, digital geological, land use and land capability maps, topographic and other environmental data. Both the electronic databank and the integrated maps are accessible from a specially designed Web page, accompanied by various WEB_GIS and multimedia applications, a VRML tour of the 3D model of Crete, statistical information (in the form of pie-charts) regarding the data of the database which are continuously updated, videos documenting the current beliefs of active archaeologists/researchers and presenting their testimonies, an inventory of the various museums existing in Crete, their location and subject, a.o. (<http://digitalcrete.ims.forth.gr/>) (Fig. 2).

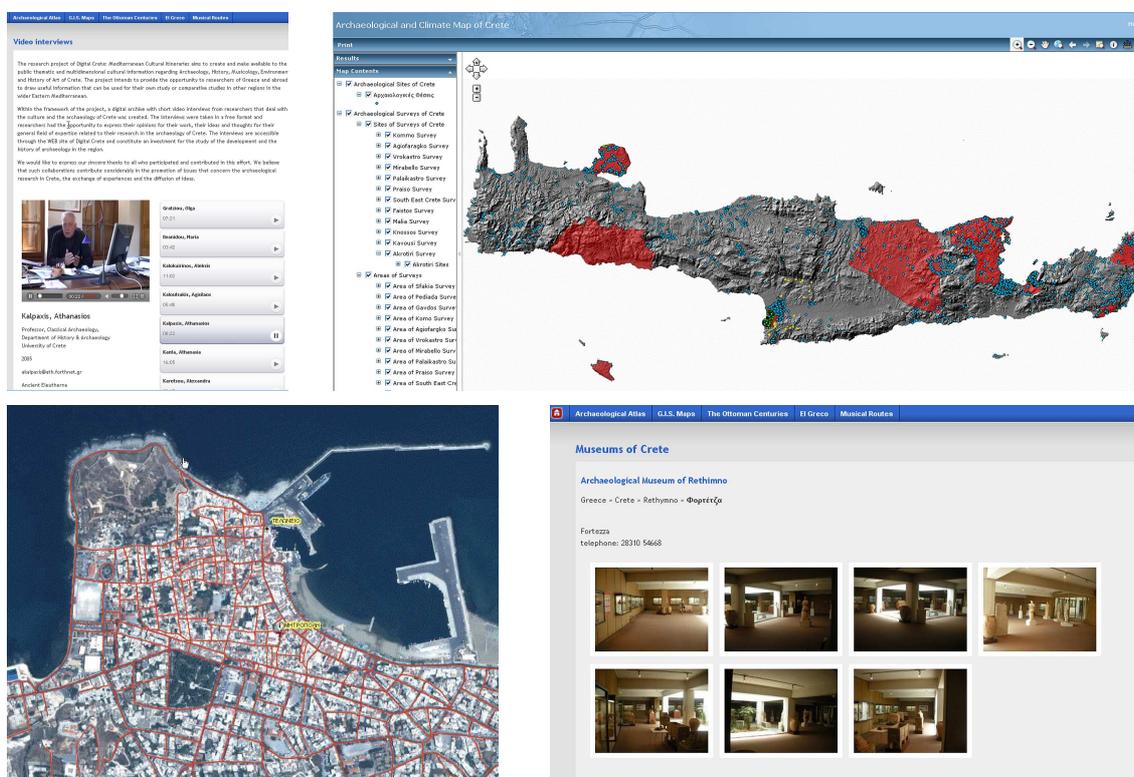


Fig. 2 – The WEB portal of *Digital Archaeological Atlas of Crete* consists hosts among others video-reviews of archaeologists and researchers (upper left), WEB_GIS applications that cover either the whole extent of the island of Crete (upper right) or of the basic urban centers-capitals (eg. high resolution satellite image of Rethymno (lower left)) of the different Prefectures of it and an electronic multimedia based inventory of the cultural centers and museums of Crete (lower right).

Mediterranean Cultural Itineraries

The project Mediterranean Medieval Places of Pilgrimage Network of the Documentation, Preservation and Enhancement of Monuments in the Euromediterranean Area (EGERIA) was carried out by the Directorate of Byzantine and Post-Byzantine Antiquities of the Hellenic Ministry of Culture and it was funded by the INTERREG IIIB/ARCHIMED program. The project was focused towards the concept of pilgrimage monuments and way that they can be used for tourist attraction, independent of cultural or religious aspects. Emphasis was provided on sites and monuments of the eastern Mediterranean region having a religious, historical and architectural significance that could be used as pilgrimage destinations of different religions. The stimulus of the project was the testimony of Egeria, an early Christian pilgrim that travelled between 381-

384 AD, who described the destinations of her travel to Sinai, Jerusalem, Constantinople, Antioche and other biblical sites.

The Lab of IMS-FORTH undertook the design and construction of the WEB site of the project which contains the cultural itineraries of EGERIA project through WEB_GIS applications. The Web site

(www.egeriaproject.net) contains information regarding the physical content of the project, its objectives, partners, actions, products, a.o. portrayed in six different domains (The Egeria Project, Project Partners, About Egeria, Pilgrimage Monuments, Itineraries, A Glimpse at the Monuments). The database is separated in two sections concerning the immovable and movable monuments, each containing 51 entries/394 photographs and 100 entries/114 photographs respectively. The above information was fed separately by the partners of the project, through a construction of a specialized internet based editing tool that allowed partners to insert the appropriate information. The GIS application includes the possible land and sea route that was followed by Egeria and her main destination stations, monuments of interest, modern features, proposed tourist itineraries, geomorphologic attributes, a.o. Furthermore, it proposes 2 different cultural/tourist itineraries inspired by popular pilgrimage sites either in the early Christian period (3rd-7th ce. AD) or in the Byzantine and Post-Byzantine periods (7th century and onwards) (Fig. 3).

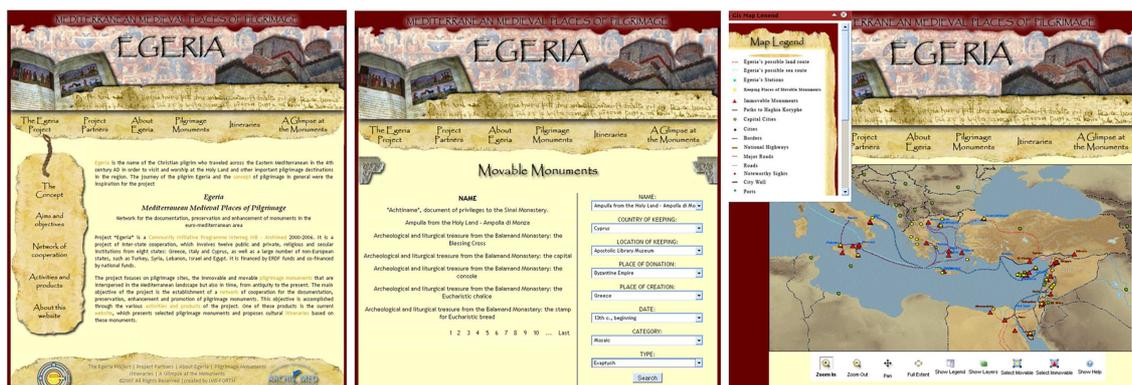


Fig. 3 – The WEB portal of the Egeria project. Except the general information about the project (left), the web site offers a dynamic database query for the movable or immovable monuments that are correlated to Egeria's pilgrimage trip (middle) and a WEB_GIS application which can be formulated according to the needs of the user in order to highlight monuments, itineraries, noteworthy sites, modern geographic features and other geospatial attributes that can help either the researchers or the potential tourists.

Similar was the aim of the project titled *Discovering "Magna Grecia" (DI.MA.)* that was also carried out under the auspices of the INTERREG IIB/ARCHIMED program. The scope of the project was the creation of tools for the protection of the cultural heritage and of the network of Parchi Letterari[®] both local and trans-national supporting the development of sustainable tourist activities. Emphasis was given to the study and mapping of itineraries, both sea and land, and monuments of the Magna Grecia. The partners of the project included the Region of Calabria, the Province of Cosenza, the Province Regional of Agrigento, the Region of East Macedonia and Thrace and the Prefecture of Rethymno.

Within the framework of the program and the collaboration with the Prefecture of Rethymno, the Lab undertook the responsibility of producing scientific documents related to the monuments and the archaeological sites of Rethymno that indicate cultural relations between Crete and Italy (Fig.4). A cultural database was created for the electronic registration of the archaeological sites and monuments of Rethymno and thematic maps that present the sites by period and the corresponding itineraries were created in a GIS platform which is also available in the WEB (http://www.ims.forth.gr/joint_projects/dima/dima.html). The

thematic maps cover the extent of Italy and Greece, whereas emphasis has been given to the archaeological sites of Rethymno related to the goals of the program. Satellite remote sensing and GIS were heavily used for the goals of the project.

Finally, we could also have to consider applications that try to combine both areas of cultural and natural significance. Such kind of projects proposes itineraries that could attract visitors that can combine outdoor recreation and cultural destinations. Foot trails, mountain climbing, river or gorge walking, can lead visitors to places of natural beauty and of historical or archaeological importance. This was exactly the goal of the *E-market-path E4: Internet Itineraries of Path E4 (Rethymno-Pafos-Larnaka)* project, which was carried out under the auspices of Interreg III Greece-Cyprus 2000-2006 program. The project aimed towards the creation of a norm of a comprehensive electronic tourism management system of the areas crossed by the E4 European path in the areas of Rethymno, Pafos and Larnaka and it was based on the re-planning of the strategic promotion of areas of cultural and natural importance that are crossed by the path in Crete and Cyprus. The multimedia web site (<http://www.e4nar.gr>) that was created by IMS-FORTH with the collaboration of the Prefecture of Rethymno, contains interactive maps accessible through WEB_GIS platforms and Google Earth APIs, 360° panoramic captures of sites of cultural importance and archaeological databases that emphasized the diachronic settlement in the Prefecture of Rethymno (Fig. 4).



Fig. 4 – The WEB_GIS portal of the DI.MA. project helps to understand the cultural ties between Crete and Italy (left). A wealth of context and multimedia information is offered on the projected itineraries of the E4 European path, combining interactive maps, photos and virtual tours from a number of sites and nodal points of natural and cultural beauty (middle and left). The users can choose the path they are interested in and both the map and the database turn to the corresponding information.

Management of Cultural Resources

The management of cultural resources and monuments can be also carried out through various internet-based applications (Cultural Resources Management Applications – CRM) that pay a lot of attention to the geographic attributes of them. These applications may concern monuments, general sites and even regions depending on their scale and range of function. An example of a monument-based CRM application has been constructed for the architectural units and interventions of the walls of Acropolis and Erechtheio. The particular application that combines a detailed database and WEB_GIS of the architectural characteristics of the monuments of the Acropolis of Athens, was constructed by IMS-FORTH for the goals of the program *Supply of Equipment and Services for the Development of GIS for Acropolis of Athens*, that was funded by the Information Society of the European Community Support framework and was carried out by the cooperation of Elliniki Photogrammetriki and Geotech Liapakis X. Balis B. companies, under the auspices of the Ministry of Culture (Acropolis Restoration Service) (MOULLOU 2008, THEODOROPOULOS & SARRIS

2009). The project combined the use of laser scanning and 3D reconstruction modelling, which were used for presentation of the monuments in the internet but also for querying purposes, based on either the location of the architectural attributes or their status of conservation and type of intervention (<http://geodigital.yisma.gr>) (Fig. 5). Data from instruments measuring the micro-movements of the walls, the temperature and other parameters were also included to the CRM application for a better management of the monuments.

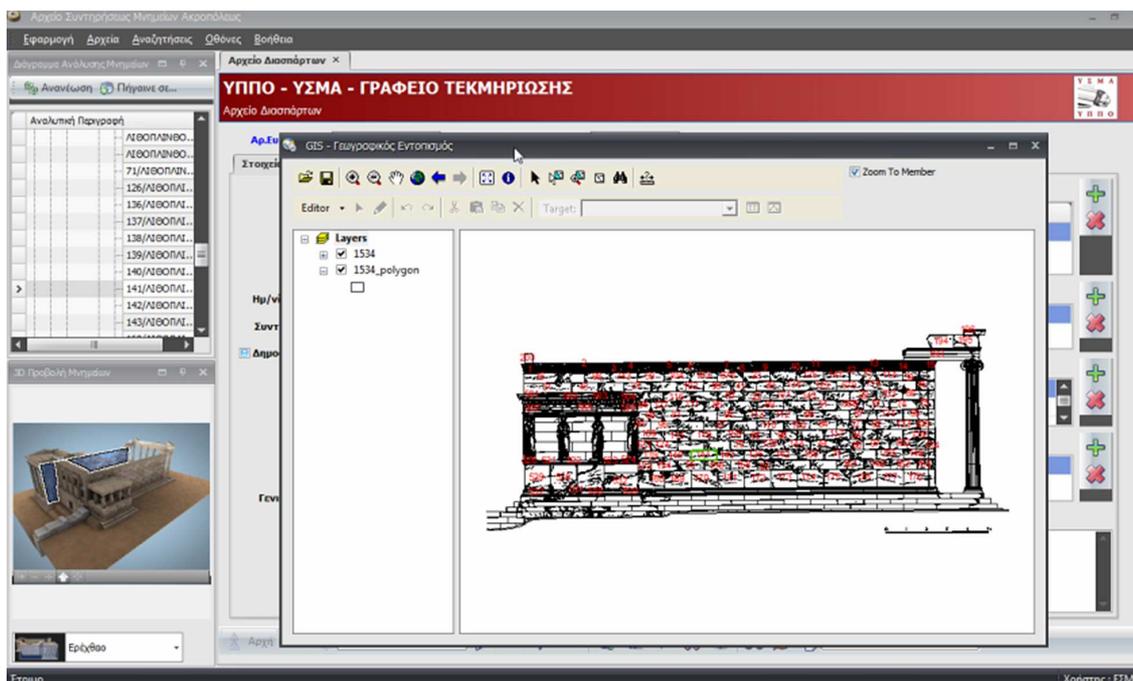


Fig. 5 – Screen snapshot of the application platform that is used for the management of the architectural elements of Erechtheio. The application connects the sections of the 3D model of the monument with the corresponding database and GIS project.

Moving to a medium-scale CRM project, *E-MEM: Interactive Graveyard Information Management tool and Virtual Memoriam Database*, proposed an internet based tool for the management and services of modern and historical cemeteries (JOHANNSON et al. 2007). The project defined the best practices for portraying information on cultural monuments in the context of graveyards and investigated the evolution of funeral practices in Europe. The changing patterns of cemetery locations were also explored by creating a number of thematic maps for the island of Crete, presenting the spatial distribution of the prehistoric and historic cemeteries, linked to multimedia information related to them.

To achieve the goals of this e-Content project, the participating members (Teikn a lofti ltd/Iceland, Comune di Bologna (COBO)/Italy, Department of Cultural Heritage Protection (DCHP)/Lithuania and IMS-FORTH/Greece) utilized mapping technologies through the use of GPS and EDM units, digitization and rectification techniques, SQL database construction, GIS mapping and presentation of the geographic information through the WEB (www.e-mem.org & http://www.ims.forth.gr/joint_projects/e-mem/the_project.htm). A number of pilot cemeteries were brought in the pool of the e-Mem portal, including the modern Orthodox cemetery of Rethymno, the Deutsche Soldaten Friedhof at Chania (Fig. 6), the Moslem Cemetery of Yeni Mahalle at Komotini, the Municipal cemetery of Bologna (Certosa cemetery) and the Bernardines Polish cemetery in Vilnius. The significant historical context of the cemeteries and their

monuments was emphasized. In this way, the project not only focused on building a dynamic portal bringing together the different policies & standards of registering and offering info on the deceased in Europe, but also on constructing a tool that could serve information related to the historical and cultural value of the cemeteries and their significant monuments.

A kind of a different approach, with large range function, was followed by the project *Advanced Techniques for Seismic RISK reduction in Mediterranean Archipelago Regions (Se_Risk)*, under the INTERREG IIIB ARCHIMED program (collaboration of the Technological Educational Institute of Crete, the Center for Technological Research of Crete, IMS-FORTH, Chania, Rethymno and Herakleion Prefectures, CNR-IMMA, the Environmental Risk Analysis and Monitoring Limited Liability Consortium Company, the Geophysical Institute of Israel and the Earth Sciences and Seismic Engineering Center (ESSEC)) (SARRIS et al. 2010). Aiming towards the deeper understanding of the physical direct damage due to earthquakes, the project concentrated on earthquake-hazard scenarios on the distinctive features of Mediterranean Archipelago towns and sub-regions, including examples from current and/or historical buildings (<http://serisk.ims.forth.gr>). Following the directions of the project, the Lab of IMS-FORTH focused on the study of the seismic hazard assessment and the vulnerability of modern and historical buildings, especially those located in the historical centers of the cities, through the construction of a GIS based prototype for the cities of Chania, Rethymno (Fig. 6) and Herakleion. The modelling parameters that were fed into the GIS platform included the historical seismic activity in the area of Crete, the statistical, geomorphological and civil attributes of the cities (such as census sector, department, building block, number of buildings & floors, chronological period of construction, main construction materials, usage type, a.o.) and they were processed using specific weights of significance in order to construct a model for the seismic hazard assessment that has a direct effect for the management of the historical and archaeological monuments of the urban centers of Crete.

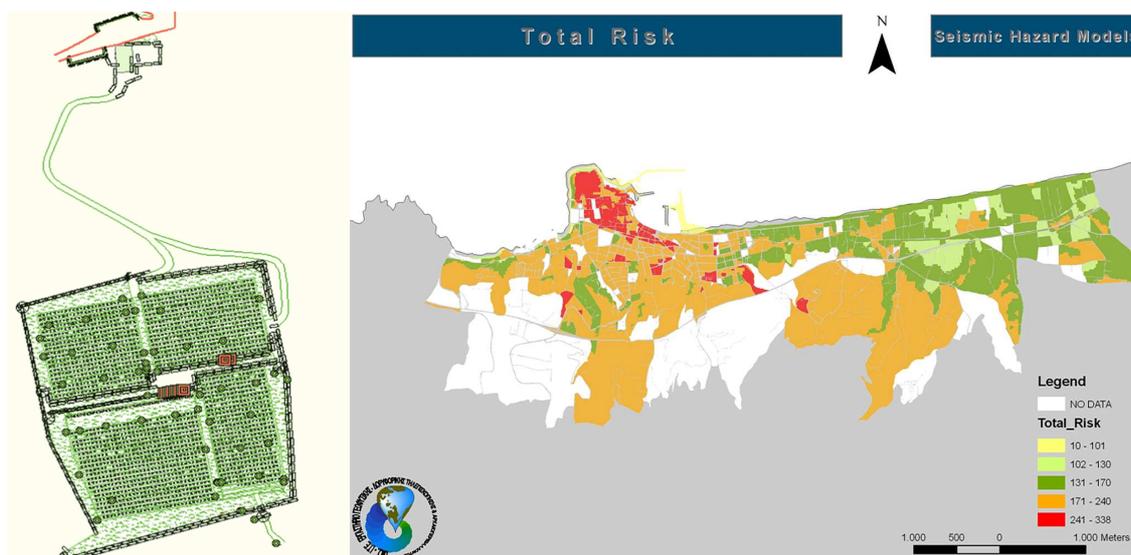


Fig. 6 – Left: A case study drawn from the e_MEM project: TheDeutsche Soldaten Friedhof, at Maleme, Chania. The cemetery contains 4,465 burials of Germans who lost their lives at Maleme and a few relocated burials from Germans who were initially buried in mass graves in the NW sector of Heraklion airport, in front of the chapel at Galatas near Chania and in the cemetery of the German parachutists fallen in Heraklion. The Web_GIS application and the accompanied database contain among others the description of the graves, names of the deceased, date of death, age and rank of the deceased. Right: The final seismic hazard assessment model for the city of Rethymno. The model was based on the synthesis of the geological and construction risk models. As it is shown, the highest degree of risk exists within the limits of the historical center of the city, where a number of Venetian and Ottoman architecture and monuments exist.

Dissemination of Research Analyses

Results from various basic and/or applied research studies and applications have rarely been hosted in a WEB_GIS platform. Such kind of applications are of vital importance to the academic community (both researchers and students) since they are able to be used for educational and training purposes, especially when they are accompanied with information regarding the spatial processing techniques that have been used in the particular case studies. Furthermore, in cases of a large scale project, it is possible to display the results of the study in a much more detailed way, allowing researchers to focus to a smaller region of their interest or even expand the conclusions of their small scale study to a regional scale.

This was exactly the purpose of the *Reconstructing the Habitational Patterns of Neolithic Thessaly* project (ALEXAKIS et al. 2008, 2009). Settled by the first farming groups of Europe around 7500 BC., Neolithic Thessaly is traditionally an interesting area for understanding human partitioning and territoriality of the landscape by non-hierarchical, 'egalitarian' human groups. Thessaly constitutes a closed geographical unity with well-defined limits and sub-divisions and thus it is ideal for reconstructing the major habitational patterns of the first Neolithic farming groups of Greece. The project, funded by INSTAP and PENED, consisted of a number of modules including a synthetic analysis (through GIS tools) of the older and recent excavations and surveys aiming to the study of the settlement patterns of the region and the employment of various satellite sensors (HYPERION, ASTER, LANDSAT, Ikonos, a.o.) for the detection of the Neolithic magoulas in order to construct a predictive model for them.

To achieve the above, a detailed archaeological database was formed that included information about the extent and location of the sites and the lithic material found at them. The location of the sites was defined through a combination of satellite images, aerial images and GPS surveys. Extensive digitization was required to produce the original DEM. Certain experiments were carried out for the detection of the Neolithic mounts based on the DEM constructed by various sources such the topography maps or the one provided by the Shuttle Radar Topography Mission (SRTM). Special attention was given to the geomorphological parameters that affecting the local relief. Data from past geological coring were gathered and contributed to the models created for landscape (DEM, coastline, a.o.) reconstruction. The later was based to the study of two major regimes, namely the tectonic and the geomorphologic regime. More spatial analyses including viewshed analysis, clustering, site catchments, density maps, buffering, least cost paths, a.o. were carried out to approach the changes of the settlement patterns of Thessaly in the different phases of the Neolithic period (Fig. 7). The results of the particular project were disseminated through a number of WEB_GIS applications (<http://neolithictliessaly.ims.forth.gr>) in order to demonstrate the importance and contribution of the above technologies in the analysis of the settlement patterns of Neolithic Thessaly and it is expected to be used as a guide for future analyses and as a training node for archaeologists that want to use similar techniques and spatial analysis.

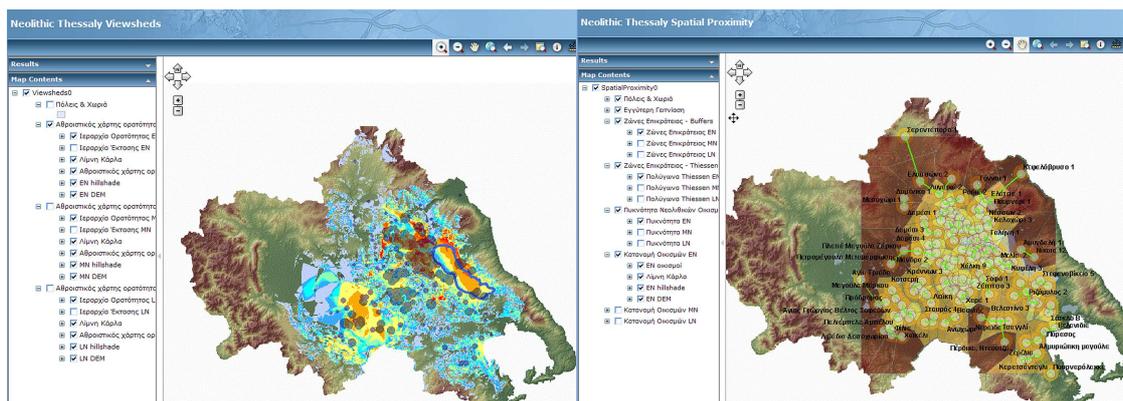


Fig. 7 – Part of the results of the *Reconstructing the Habitational Patterns of Neolithic Thessaly* project that are available in the internet: Hierarchical viewshed analysis (left) and site catchments based on Thiessen polygons (right) for the Neolithic magoulas of Thessaly. The results/maps of the project are also accompanied with metadata and textual information that explain the methodology that was followed as a way of educating/training of specialists on the methodological tools of GIS spatial analyses.

Concluding Remarks

The above manifest the different ways of internet based applications and tools for the promotion, information dissemination of Cultural Heritage sites and management of monuments. The coupling among various forms and media of information transmission has altered the way we search for spatial information of archaeological context. The attractive character of the archaeological inventories, integrated with a wealth of geo-information applications, 3D models and interactive panoramas or statistical data, accompanied by video testimonies of the active professionals and researchers, contributes towards the enhancement of the awareness of the wider public and provide a nodal point of reference for researchers. Except their usage for educational/research purposes and /or as means for tourist or management applications, the particular projects aim towards a better understanding of the cultural landscape and the closer contact of the antiquities with the wider public. Future information technologies will keep surprising us pushing towards more immersive applications and interactive agent-based environments, allowing us to bridge the past and the present in much more realistic ways.

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Appendix 2008

Le Stratifiant : a simple tool for processing stratigraphic data*

* This paper has been presented at the 13th Congress in 2008

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Abstract: This paper presents an application (*Le Stratifiant*) which makes it possible to create automatically stratigraphic diagrams. *Le Stratifiant* uses a simple algorithm, based on an adjacency matrix. It provides a graphic representation slightly different from the Harris Matrix, in order to avoid ambiguities, and to represent more easily different types of relationship. It can also process indicators of dating (terminus post quem, terminus ante quem), in order to assign a bracket of dating to each stratigraphic unit, and to visualise these brackets. Another important characteristic, which is also a methodological choice, is the possibility of processing two levels of relations: normal, or uncertain.

Le Stratifiant is developed on a preexisting software (Microsoft Excel). This choice allows to benefit from all the possibilities of this common software, like import – exports files and communication with data bases.

Zusammenfassung: Dieses Dokument stellt eine Anwendung (Le Stratifiant) vor, die erlaubt, stratigraphische Diagramme automatisch zu schaffen. Le Stratifiant gebraucht einen einfachen Algorithmus, der auf einer Matrize "adjacence" basiert. Er liefert eine im Verhältnis zur Harris Matrix leicht andere grafische Darstellung, um Zweideutigkeiten zu vermeiden und leichter verschiedene Beziehungen darzustellen. Er kann auch Zeitbestimmungsindikatoren (terminus post quem, terminus ante quem) behandeln, um einen Datenträger für jede stratigraphische Einheit zu bestimmen und diese Einheit zu visualisieren. Eine andere wichtige Eigenschaft, die auch eine methodologische Wahl ist, ist die Möglichkeit, zwei Beziehungsebenen zu behandeln: normal oder unsicher.

Le Stratifiant ist auf einer bestehenden Software (Microsoft Excel) entwickelt. Diese Wahl erlaubt, von allen Möglichkeiten dieser Software zu profitieren, wie Dokumentenimport oder -export und die Kommunikation mit Datenbanken.

Keywords: archaeological stratigraphy; Harris Matrix computerized application

Introduction

The way chosen for the application presented here is to exploit the possibilities of one of the most known softwares in the world, set up in most computers - *Microsoft Excel* -, in order to create a simple tool for processing stratigraphic data. *Excel* is a very common spreadsheet ; but it is also a development tool, which allows to create specific applications, without acquisition of a new software, and remaining in the same well-known environment of work. The tool presented here, called *Le Stratifiant*, comes as an *Excel* file. It may be moved and copied like any other *Excel* file. But when it is opened, some specific characteristics appear : it contains a program written in *VBA* (the Microsoft application programming language), preset sheets to receive the data, and buttons and controls which allows to operate the data processing exposed below.

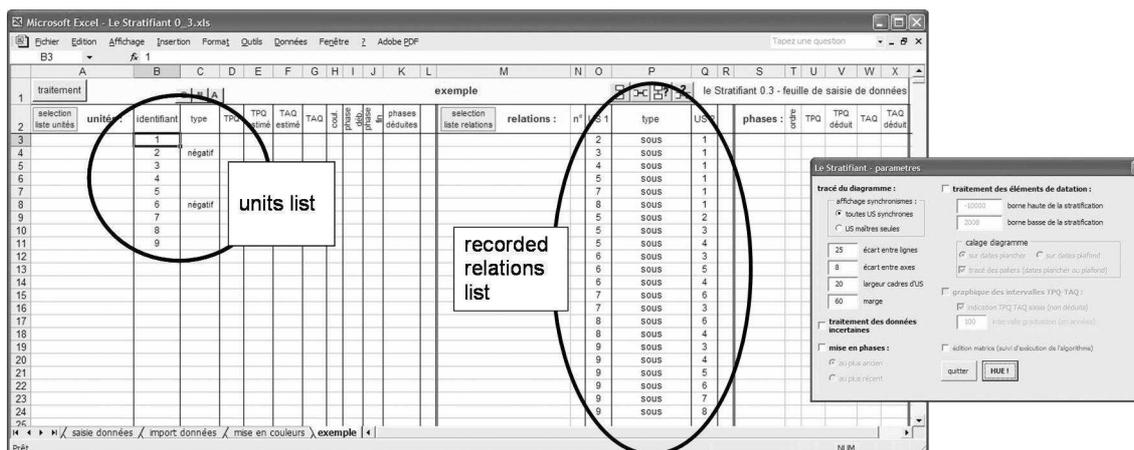


Fig. 1 – Data sheet and options window in *Le Stratifiant*

Formal view of stratigraphic relations

All the existing stratigraphic data processing tools, *Le Stratifiant* included, need to represent stratigraphic relations by mathematical relations with defined properties. Mathematically, anteriority ("prior to") and posteriority ("after") relations are reciprocal partial orders (ORTON 1980), according to their properties :

- irreflexivity (a layer can't be prior to itself) ;
- transitivity (if a layer is prior to another layer, and if this second layer is prior to a third layer, then the first one is prior to the third one) ;
- antisymmetry (if, like Clive Orton, we regard stratigraphic relations as a non-strict partial order, so that if a layer A is prior to a layer B, and symmetrically if B is prior to A, then A and B are the same layer), or asymmetry (if we regard stratigraphic relations as strict partial orders, so that if A is prior to B, then B can't be prior to A).

As representation of a partial order, the "Harris matrix" comes under the graph theory: it is formally an oriented graph, made of nodes (the stratigraphic units) and arcs (the lines joining the units). Ancestors of the Harris matrix may be found in some specific applications of graph theory : the tasks scheduling graphs, perfected in the years 1950 to manage complex industrial and military production processes. The most known of these ones is PERT (Program (ou project) Evaluation and Review Technique) chart, created in 1957 to manage the development of the US Polaris strategic missile. In a PERT graph, events, which are typically tasks of a production process (for instance "set windscreen" in a cars assembly line), are represented by arcs. The node between two successive arcs represent the "precedence constraint" between the two tasks : (for instance, to build a car, « set windscreen » and « windscreen wipers »). Another tasks scheduling technique is the MPM (Méthode des Potentiels Métra) graph, designed since 1959 by the mathematician Bernard Roy (ROY 1959, FAURE LEMAIRE PICOULEAU 2000). In this graph, nodes are tasks, and arcs are precedence constraints. The MPM graph is more in accordance with graph theory and so it is more efficient (it doesn't need to insert a "dummy task" to complete the graph when a task has several prior events).

It is easy to see how the tasks scheduling problems are related to the archaeological stratigraphic problems: a stratigraphic unit may be regarded as a "fossil event" in a site formation process ; and the stratigraphic relations are the precedence constraints between these "fossil events". From this point of view, the MPM

graph is formally very close to the Harris matrix (DESACHY DJINDJIAN 1990). So, the process exposed below is greatly inspired by these tasks scheduling techniques and particularly by the MPM technique.

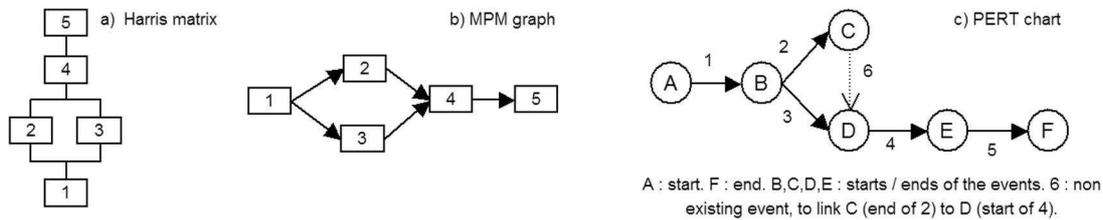


Fig. 2 – representations of a partially ordered sequence of five events : a) Harris Matrix , b) MPM graph, c) PERT chart. In the two former cases, the events are represented by the nodes. In the third case, the events are represented by arcs (lines) ; a “dummy” (non existing) event must be added to represent the complete precedence constraints.

Archaeologists record not only anteriority or posteriority relations, but also stratigraphic synchronisms. As we can consider antéro-posteriority to be a mathematical partial order, we can theoretically regard those stratigraphic synchronisms as a mathematical equivalence, with its properties of reflexivity (a layer is synchronous with itself), transitivity (if a layer is synchronous with an another one, and if this second layer is synchronous with a third layer, then the first one is synchronous with the third one), and symmetry (if a layer A is synchronous with a layer B, then B is synchronous with A). However, in some cases, this mathematical relation of equivalence is not sufficient to take in account the whole notion of stratigraphic synchronism (or "correlation") practically used by the archeologists (what we will discuss below).

Stratigraphic data processing

Like tasks scheduling graphs and other oriented graphs, Stratigraphic diagram can be built with two sets: the set of nodes and the set of oriented pairs of nodes which define the arcs. The archaeological observations provide these two sets, which are the list of the units, and the list of the elementary recorded relations (pairs of units). These two lists must be entered in *Le Stratifiant*, in the appropriate sheet (Fig. 1). The kind of relation must be indicated: antero-posteriority, or synchronism. The relations must be entered in *Le Stratifiant* in the way of anteriority (the first unit is the anterior one; the second is the later one). These lists may be directly keyboarded, or copied and pasted, or imported from a data base.

The process is based on an adjacency matrix. This data structure, used by some authors (DESACHY DJINDJIAN 1990, SHARON 1996), has a disadvantage (HERZOG 1993): the storage requirement increase exponentially with the number of stratigraphic units. But it has significant advantages: a great simplicity of process, just by scanning the matrix; and all the relations can be stored in it, even the logically impossible ones, so the detection of the recording faults is easy.

Starting from the lists of recorded units and relations, the matrix is coded with the units in rows and columns (by convention, the posterior units are the columns; the former units are the rows). The order recorded relations are coded in the squares (value 1).

Then, these matrix order values are completed and recalculated, and all the purely logical relations (not materialized in interfaces) are transitively deduced, by scanning the matrix, using the formula :

if matrix(i, j) <> 0 and if matrix(j, k) <> 0, then matrix(i, k) = matrix(i, j) + matrix(j, k).

Several iterations may be necessary. At the end of the calculation, for each pair of units, the obtained value is the stratigraphic distance, *i.e.* the number of stratigraphic steps between the two units. If a unit is directly above another one, the stratigraphic distance remains 1. "Redundant" (transitively deductible) relations have distances higher than 1. A value 0 means that the two units are not in relations. Then, for each unit, all its former units appear in its column with their order given by the stratigraphic distance; and in the same way, all its posterior units appear in its row.

Each unit has a distance from the oldest, *i.e.* the beginning of the sequence (the higher value in its column), and a distance from the most recent, *i.e.* the end of the sequence (the higher value in its row). These distances from the end and the beginning of the sequence will define the stratigraphic rank and the height of the unit in the diagram.

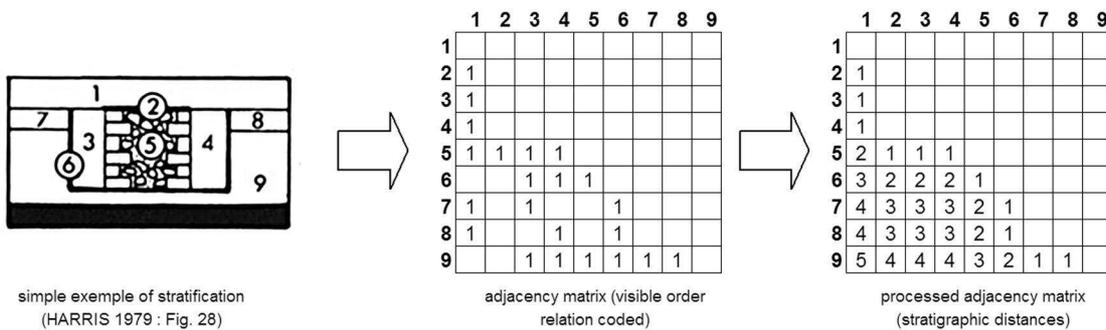


Fig. 3 – simple example (HARRIS 1979): adjacency matrix, coded and processed order relations.

Graph drawing

The graphs produced by *Le Stratifiant* are quite different from the traditional Harris diagrams (and from the graphic form of MPM or PERT graphs). Relations are always represented by right lines, never by broken lines. The orientation of lines has a strict significance. Lines are either vertical, or horizontal. Vertical lines represent relations of stratigraphic order (anteriority, posteriority). Horizontal lines represent relations of stratigraphic equivalence (synchronism).

To respect these conventions, if a unit has several non redundant former or posterior ones, it is necessary to repeat this unit; in synchronic (equivalence) relation with itself (this reflexive equivalence relation is marked by a double horizontal line).

This graphic form has been chosen because it has a clear graphic logic which avoids ambiguities (some ambiguities are possible with the Harris classical form : BIBBY 1993, ROSKAMS 2001), and it is easy to build (even by hand).

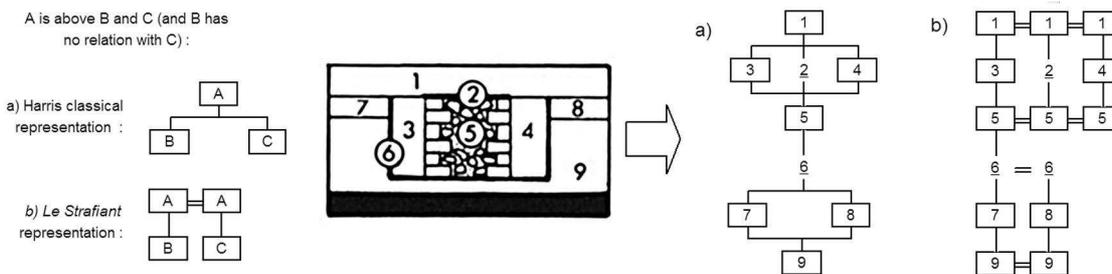


Fig. 4 - Harris and *Le Stratifiant* representations.

The diagram is drawn, path after path, by scanning the processed adjacency matrix, using only values 1 (no redundant relations), are not drawn. So, *Le Stratifiant* respects a basic principle of the Harris matrix (known as the "fourth law" or Harris): showing all the chronological sequence deduced from the stratigraphy, but only this relative chronological sequence (and not the whole physical stratigraphy).

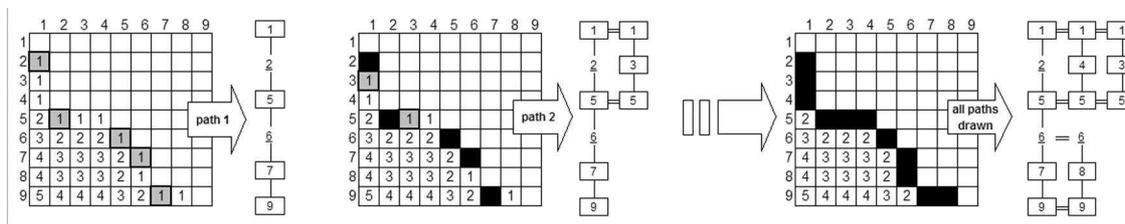


Fig. 5 – each path of the diagram is drawn by scanning the matrix, using the values 1 (non redundant relations).

The order of scanning matrix influences the shape of the diagram. At this stage, there are some instructions in order to reduce crossings between horizontal and vertical lines (in other words, in order to improve the planarity of the graph). Anyway, with the form of diagram produced by *Le Stratifiant*, these crossings are not so annoying. Indeed, it's impossible to confuse them with relations, because relations are never represented by broken lines. At the end of the process, the redundant relations, not displayed on the diagram, are displayed in gray in the list of the relations (on the data sheet showed Fig. 1).

Synchronisms and uncertain relations

The main specific characteristic of *Le Stratifiant* is to manage two levels of relation: certain relations, and dubious or uncertain relations.

This distinction is useful, first, to deal with the relations of synchronism. It allows to clarify some ambiguities which often stick to these relations. In the example shown in the figures, Harris indicates what he calls a "correlation" between the two units 7 and 8 (supposed to be the same unit at the beginning). There are two ways to consider this "correlation".

On one hand, we can estimate that this common origin of the two layers is certain. In this case, layers 7 and 8 are indeed the same stratigraphic unit. So, this correlation is a real synchronism; in other words, a relation of stratigraphic equivalence. So, following the rules fixed by Harris himself, the redundant relations must be removed. The representation of the stratigraphic sequence is thus simplified (Fig. 6a). Practically, the synchronous units, identified by a specific coding value of synchronisms in the adjacency matrix, are merged during the process, before treating the order relations.

On the other hand, we can estimate that the common origin of these two layers is only an assumption of the archaeologist, not a certain fact. The example of Harris seems to come under this case of uncertain relation: as Steve Roskams said (ROSKAMS 2001), this correlation is not based on a direct observation of a physical continuity, but only on an extrapolation. In this case, the two units are placed at the same height and are connected visually in the diagram, but they are not merged during the process (Fig 6b). The rule of elimination of the redundant relations does not apply.

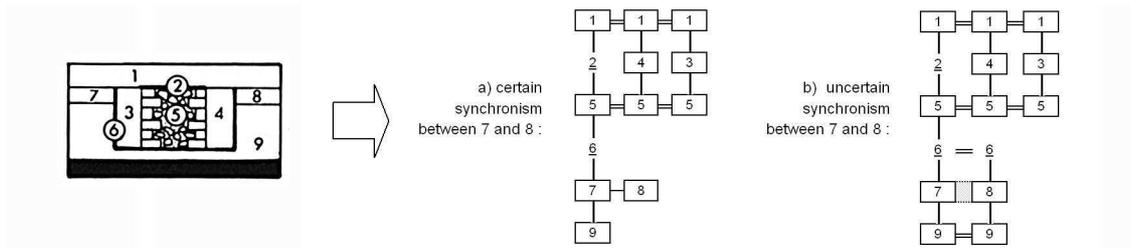


Fig. 6 – certain synchronism (with elimination of redundant relations) and uncertain synchronism with *Le Stratifiant*.

If we consider these two levels of relation (certain and uncertain), we think that the relation of certain synchronism is to be reserved when a continuity or intrication between two units is directly observed, so that they constitute, with no doubts, only one stratigraphic step. Such synchronic units may be distinguished because of their different nature (for example a buried corpse and the funerary deposit which accompanies it) or simply for technical reasons, (for instance a wall, renumbered in two different sectors of excavation). Anyway, It is the responsibility of the archaeologist to define the level of its observation, as certain or dubious. *Le Stratifiant* processes the data accordingly.

These two levels may, and logically must, be also applicable to the anteriority and posteriority relations. They allow to manage cases of uncertainty of stratigraphic succession; which are possible, for instance in the recording of standing structures. Practically, the uncertain order relations are represented by vertical dotted lines.

The uncertain character of an order relation results in a restriction of the rule of elimination of the redundant ones. This rule is segmented: a certain relation is regarded as redundant (thus eliminated from the diagram), only compared to the relations of the same mode (certain). So, a certain relation, redundant only compared to an uncertain one, will be drawn on the diagram because it shows the continuity of the certain chronology. Uncertain relations are identified by negative values in the adjacency matrix (in this case, the stratigraphic distance is calculated with the absolute value).

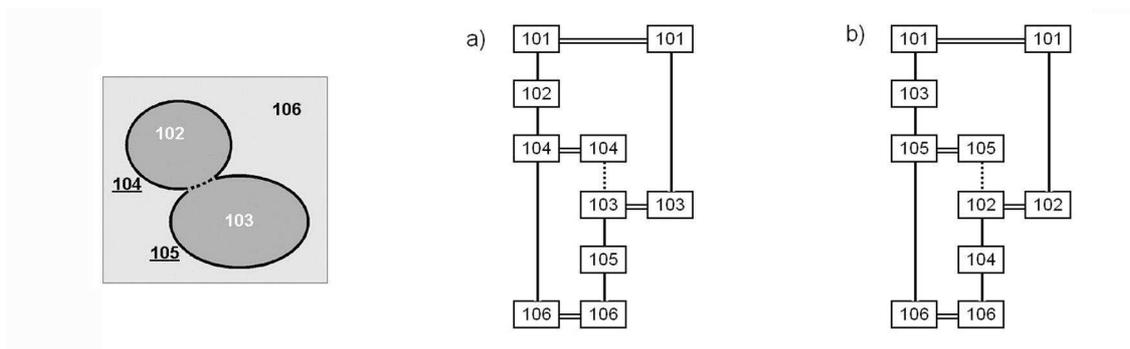


Fig. 7 – Uncertain order relation between two pits: the archaeologist thinks the pit (104, 102) cuts the pit (105, 103), but he is not sure. This uncertain relation is specifically displayed on the diagram (dotted line), with “redundant” certain relations to keep the continuity of the certain chronology (a). If other searchers are not convinced by the archaeologist arguments about this dubious relation, an another chronology may be suggested ; but the certain relations don’t change (b).

From stratigraphic data to quantified time

Le Stratifiant offers a function of inscription of the stratigraphic sequence in the quantified absolute time, if at least few units have known indicators of dating, terminus post quem (TPQ) or terminus ante quem (TAQ), provided by historical evidences or post-excavation analysis.

Before presenting this function, it is necessary to remind, or make clearer, some points about the relationships between the ordered stratigraphic time and the quantified absolute time.

Into the quantified time, a stratigraphic unit has duration of formation, which is a length of time, with a beginning and an end. Like a precedence constraint in a PERT or MPM graph, an elementary stratigraphic relation between two units may itself represent a length of time: the time between the end of formation of the anterior unit, and the beginning of formation of the later one.

From this point of view, we must notice that a Harris matrix gives a defined – and so, limited – information; it represents each unit at a specific point in the quantified time: the end of formation. The diagram only gives the succession of the moments of end of formation of the units; it tells nothing about other chronological information. For instance, it tells nothing about formation durations of the units. The Harris matrix is a useful tool, but not a universal chronological tool.

However, for the archeologists, this moment of end of formation of a unit is important, because it is this moment which is limited by the common indicators of dating: TPQ (after which the end of the formation of the unit is necessary placed) and TAQ (before which the end of the formation of the unit is necessary placed). In fact, this specific point in the time – the end of formation of the unit – corresponds with what is generally understood by “date” of the unit (although this notion of date of an archaeological layer may be sometimes ambiguous).

The relation between the date of a unit (according to the definition above: the final moment of formation) and its TPQ is a partial order (equal or later than), like the stratigraphic relations. So TPQ and TAQ can be transferred by the way of stratigraphic relations and their property of transitivity. If a unit i is prior to a unit j , and if the TPQ of i is the year y , then we can write :

$$y \leq \text{date}(i) < \text{date}(j) ; \text{so} : y \leq \text{date}(j) ;$$

And vice-versa, if the TAQ of j is the year z :

$$\text{date}(i) < \text{date}(j) \leq z ; \text{so} : \text{date}(i) \leq z$$

These transfers are usually practised, but often empirically and incompletely. *Le Stratifiant* allows to systematize them, for the whole recorded stratification.

We can remark that the other moments and lengths in time mentioned above – the lengths of formation of units, the moments of beginning of formation, the lengths of time represented by the relations themselves – may sometimes be estimated with intervals, like the TPQ - TAQ intervals. Then, they could be integrated in these systems of inequations based on the stratigraphic relations (DESACHY 2008). Processing such completed systems of inequations is the next step of development of *Le Stratifiant* ; at present it processes only TPQ-TAQ indicators.

Practically, it is necessary to choose an "absolute" TPQ and an "absolute" TAQ, valid with no doubt for the whole recorded stratification (for example the date of the beginning of the excavation for TAQ). At the beginning of the process, all the units have this interval.

If a layer has a specific TPQ (provided for instance by a datable artifact, or by a radiocarbon analysis...), this one is transferred via stratigraphy on the posterior layers (except for the posteriors units which have more recent TPQ); and vice versa, each specific TAQ is transferred on the prior units ; so that the TPQ-TAQ interval of each unit is recalculated.

After these transfers, the units may be sorted into TPQ order, before drawing the diagram. Thresholds corresponding to the TPQ are drawn in the diagram (red horizontal dotted lines); so that the first threshold line under a unit is its TPQ. In other words, the diagram has a layout fixed at the earliest in the quantified time.

The other choice is sorting the units into TAQ order. Then, the process leads to a diagram fixed on the TAQ: so that the first threshold line above a unit is its TAQ. In other words the diagram has a layout fixed at the latest.

So, starting from a recorded stratification with some TPQ and TAQ, *Le Stratifiant* can provide not just one diagram, but two: one fixed on the TPQ (Fig. 8a) and other one fixed on the TAQ (Fig. 8b). It is not possible to represent both TPQ and TAQ by horizontal thresholds lines on the same diagram, because of the disparity of the intervals TPQ-TAQ (in other words, because the imprecision of dating is not constant).

These two diagrams are the two extreme shapes that the diagram can take according to the chronological quantified indicators. The archaeologist may choose, between these two extremes, one or different intermediary layouts. For that, he can modify the diagram obtained automatically, as we will see below. To represent easily the TPQ – TAQ intervals, it is necessary to use a chart specifically based on a quantified scale of time. This TPQ – TAQ intervals chart is the third document resulting from the process, complementary to the diagrams (Fig. 8c).

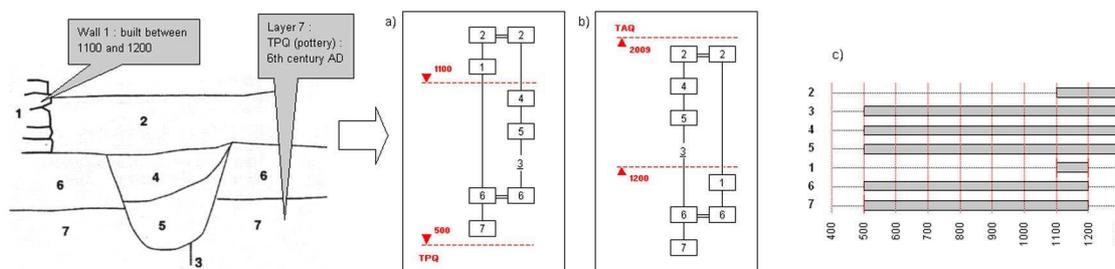


Fig. 8 – diagram fixed on the TPQ (a), diagram fixed on the TAQ (b), and TPQ-TAQ intervals chart (c).

Le Stratifiant has also a function of assistance to phasing, starting from indications of phase given by the archaeologist for at least a part of the units (Fig. 11). If the user hesitates to allot a unit to a phase or to another one, he can allot a phase at the earliest and a phase at the latest. Then *le Stratifiant* provides a general phasing either at the earliest, or at the latest.

TPQ and TAQ can be allotted to the phases. These phases TPQ and TAQ are then also used to calculate the TPQ-TAQ interval of each unit.

Detection of recording logical faults

Another important characteristic of *Le Stratifiant* is to provide detailed information on the logical faults of recording, in order to help the user to control and manage better his recording.

However, some faults of stratigraphic recording are not detectable by an automatic device, because they do not involve inconsistencies. It is possible to detect only the faults which involve illogical result, generating cycles in the stratigraphic sequence. With *Le Stratifiant*, those recording logical faults are detected by appearance of symmetrical and reflexive relations (resulting in values other than 0 in the diagonal of the adjacency matrix), during the order relations process. It allows to identify the cycles, with the involved units and relations. In this case, the process is stopped. Units and relations involved in cycle are marked on the data sheet. Then, it is the responsibility of the archaeologist to check the recorded data and to correct them. In the worst case, if the error cannot be precisely localized, the two ways of dealing with the problem are : a) eliminating all the relations involved in the cycle, or b) to amalgamate in only one unit all the layer implied in a cycle (by application of the property of antisymetry). The cycle should not be cut at random, because according to the place of the cut, it may be obtained different logical sequences, but each other contradictory.

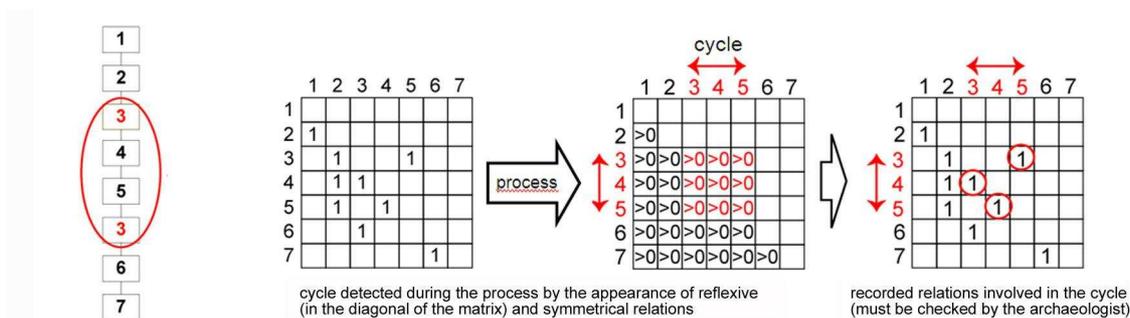


Fig. 9 – detection of a cycle in order relations.

The existence of uncertain relations involves several cases of conflicts between relations: simple contradiction (with certain relations), contradictory uncertainty (with uncertain relations), invalidation (between uncertain and certain relations), or confirmation (case which is not a conflict, between uncertain and certain relations). If these cases are detected, they are specified on the datasheet.

Diagram manual modifications

As shown above, different diagram layouts are possible on the basis of the same set of stratigraphic relations. The shape of a diagram can be modified by taking account of different information (uncertain relations, chronological thresholds, phasing...). The introduction of these non stratigraphic elements reduces the number of possible diagram layouts with the same stratigraphic relations (BIBBY 2002). This appears for instance with the TPQ and TAQ thresholds mentioned above, which give the two possible extreme shapes of diagram compatible with the known data of absolute chronology. However, even if it includes these data, a diagram may have a great number of different layouts displaying different possible chronologies, because the site chronology (of which stratigraphy is only one part) is generally not completely known. Then, the

archaeologist has to choose, and to argue for, a chronological model compatible with stratigraphy and the other data. So, we think that the final layout of the diagram, which displays this model, comes under the choice of the archaeologist, for the best expression of both the stratigraphic sequence (which of course shouldn't be altered), and the chronological interpretation based on this sequence.

Practically, the drawing tools of Excel (or other software) may be used to modify the diagram obtained, and to add indications like frames showing units groups (features, structures...). For the future, we consider procedures of assistance to these modifications by user (for example by indicating when a modification is illogical).

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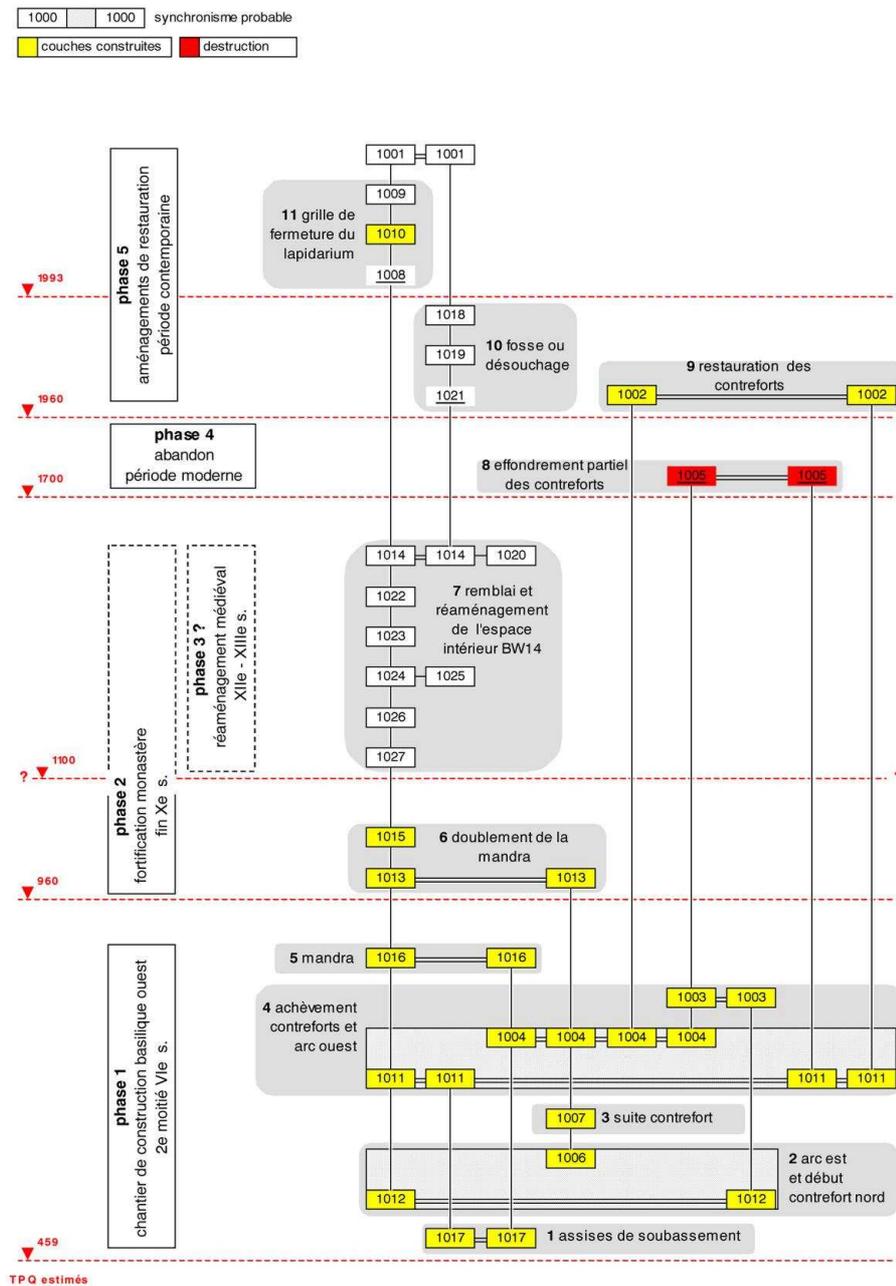


Fig. 10 – Example of diagram obtained with Le *Stratifiant*, and then modified manually to show units groups (Qal'at Sem'an excavations, Syria, 2007).

Processing data from a database

Le Stratifiant may work with, or without, a local recording database or archaeological information system. If a database management system is employed to record stratigraphic observations and other field data (what is now frequent), *Le Stratifiant* can use the communication abilities of Excel to process data imported from the database, on condition that this database is able to generate and export two distinct tables: a table of units and a table of relations (pairs of units). That implies that the database must have a relational structure to manage units and stratigraphic relations.

Two main functions are at present allowed by this communication between *Le Stratifiant* and a recording database. The first one is generating diagrams with all the recorded units, or just with a selection of units; the second one is illustrating queries made in the database on the units, by coloring these units in the diagram (Fig. 11). Then, the diagram becomes a modifiable and dynamic document (like spatial representations in GIS).

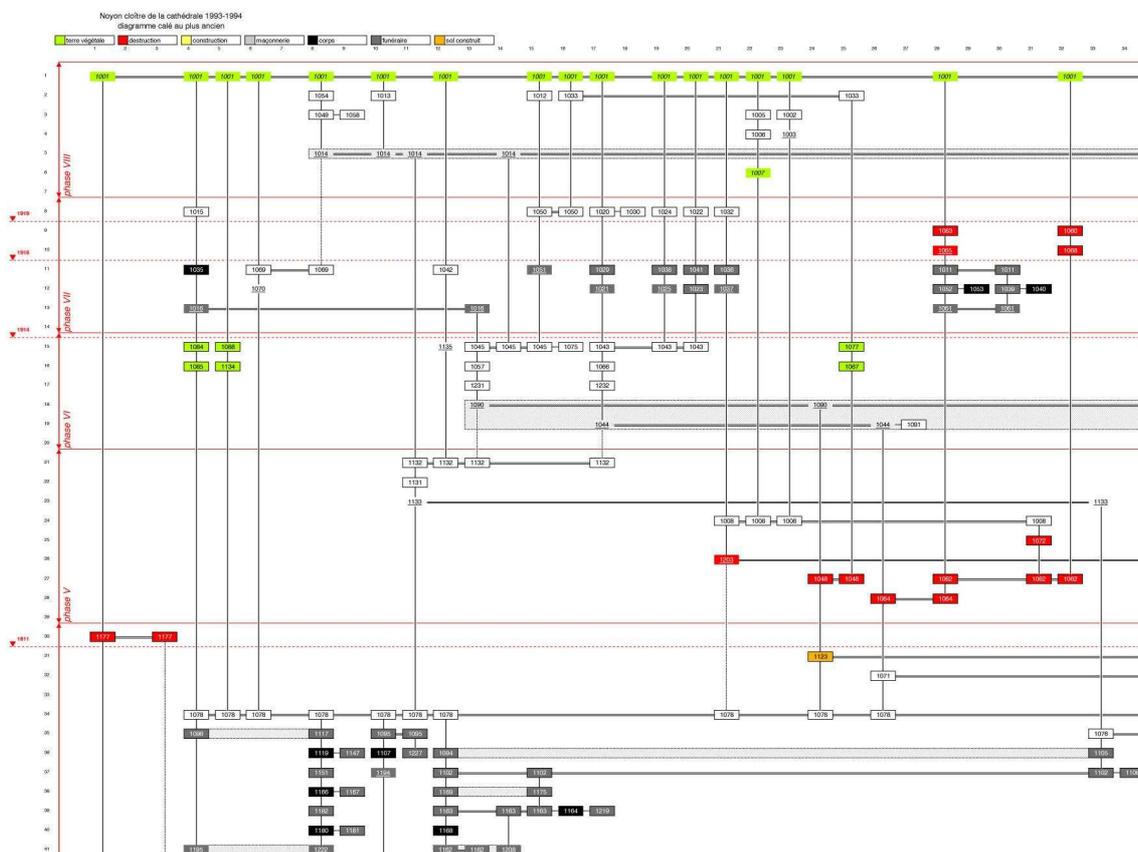


Fig. 11 - Detail from a diagram obtained with *Le Stratifiant*, with use of phasing, TPQ thresholds, and coloring functions. (Noyon, cathedral cloister – DESACHY 2008).

Experimentation and development

Le Stratifiant is a work in progress: it is at present on trials on several archaeological excavations in France (Bibracte european archaeological centre in Burgundy, Noyon in Picardy, Chinon in the Loire valley) and Syria (Qal'at Sem'an). These tests allow to find and solve bugs, and to define development prospects.

The application is contained in a PhD thesis (DESACHY 2008), in which the principles and the algorithm used by *le Stratifiant* are discussed. Both the thesis and the application are available (free download): <http://tel.archives-ouvertes.fr/tel-00406241/en/>

The current release is at present in French only, but an English version (or an attempt of it) is planned in the next months. Another evolution envisaged in a few months is a version for the free software Open Office.

Conclusion

Various choices are possible to design a tool for processing stratigraphic data. We think it is a good thing that several applications exist, like *Stratify*¹⁶⁰, *Arched*¹⁶¹, *Harris Matrix Composer*¹⁶², *Le Stratifiant*, and others, expressing these different choices of design and use. The choices materialized by *Le Stratifiant* - and thus its limits - are clear:

- choice of basic technical and software solutions, compatible with the ordinary not high level of computer equipment and practice which characterize the most part of the present archeological fieldwork (at least in France), and compatible with the rescue archaeology constraints.
- choice of basic and simple processing functions (and not advanced functions, like probabilistic chronological modeling, or 3D spatial processing...), in order to check and exploit more easily the recorded data, so that the archeologist may visualize quickly the whole results and logical consequences of his stratigraphic recording, including confrontation with absolute dating. This is a limited and practical aim, but we think it is a fundamental need (particularly in rescue archaeology conditions), to improve fieldwork management and results;
- choice to take in account the empirical nature of the archaeological approach, by including the distinction between "certain" and "uncertain" modes. "Empirical" does not mean "non scientific"; quite the reverse, we think this distinction certain / uncertain helps to keep the archaeological fieldwork rigorous and scientific;
- and, last but not least, choice to allow the user to have the last word. As it is said above, *Le Stratifiant* allows the archaeologist to visualize the consequences, and sometimes the contradictions, resulting from his observations. But the archeologist is responsible for these observations, and for their level (certain or uncertain); and finally, among the different possible layouts of diagram on the basis of the same stratigraphic structure, the final choice remains entirely under his responsibility. In short, the "philosophy" of *Le stratifiant* is: "for better or worse, the archeologist decides ; not the computer".

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¹⁶⁰ <http://www.stratify.org>

¹⁶¹ <http://www.ads.tuwien.ac.at/arched/>

¹⁶² <http://www.harrismatrixcomposer.com>

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