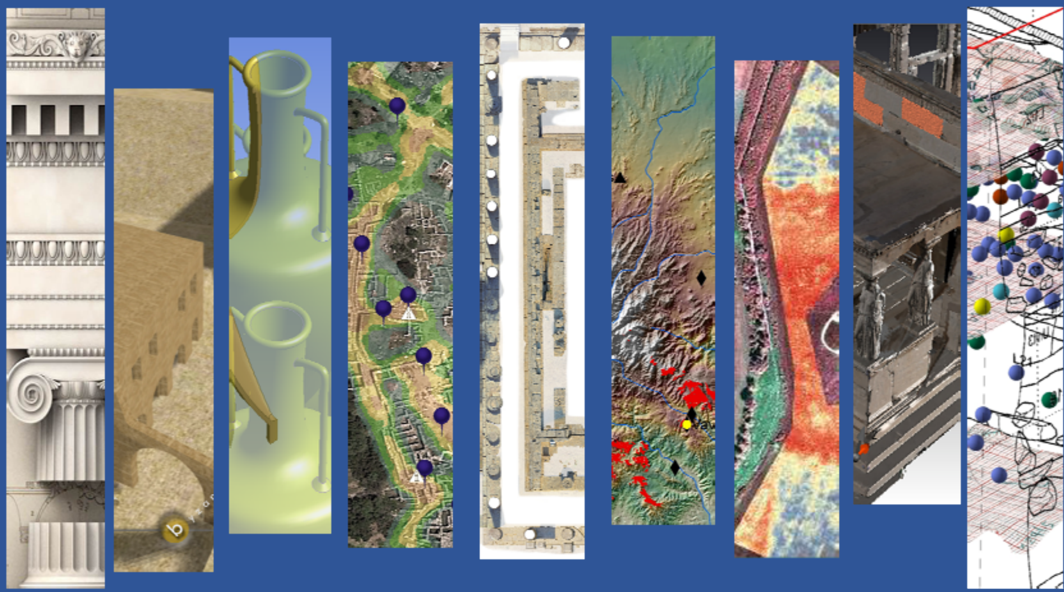

Archaeological Research in the Digital Age

Proceedings of the 1st Conference on Computer Applications and Quantitative Methods in Archaeology Greek Chapter (CAA-GR)

Rethymno, Crete, 6-8 March 2014

Edited by

Constantinos Papadopoulos, Eleftheria Paliou Angeliki Chrysanthi, Eleni Kotoula and Apostolos Sarris

CAA Greece

FORTH Institute for Mediterranean Studies

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Computer Applications and Quantitative Methods in Archaeology – Greek Chapter
CAA-GR

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Preface

The organisation of the 1st conference on Computer Applications and Quantitative Methods in Archaeology in Greece (CAA-GR) and the publication of its proceedings have been the culminating events of CAA Greek Chapter since its formation at the International CAA meeting in 2012 in Southampton. The need of Greek Chapter sprang out from the continuously increasing number of researchers dealing with the application of Informatics in archaeology in Greece and in the wider region of Eastern Mediterranean. Broadly defined, Archaeological Informatics embraces a number of disciplines from computer science, geoinformatics, image processing, architecture, statistical analysis, computer simulation, agent based modelling, virtual reality, cultural heritage, museum studies, conservation, and so forth. The dynamic momentum of these disciplines in archaeological research is manifested by the large number of members (146) from Greece, Italy, Cyprus, UK, Spain, Turkey, Austria, Belgium, Germany, Ukraine and Serbia that have already joined CAA-GR.

The goal of CAA-GR is to contribute to the broadening of Digital Archaeology and to address the theoretical and practical issues associated with the discipline. It aims to encourage communication among researchers with diverse backgrounds, to bridge the gap between traditional archaeological research and new technologies, to give rise to debate and future progress, to provide guidance and support in the form of seminars and workshops, and to disseminate the results of research presented in scientific meetings organised by CAA-GR. The 1st CAA-GR conference has to be considered only as a starting point, since it is the first time that specialists in the above domains had the chance to meet in Greece, share their experiences and exchange their knowledge. The question that remains to be addressed in the following years is what the CAA-GR community expects from Computational Archaeology? CAA-GR is a community organisation formed of researchers with common interests who give life to its existence. And as such it is the community of CAA-GR members that will be responsible for its future sustainability and evolution. We hope that the voice of the CAA-GR community will become louder in the coming years.

We would like to express our gratitude to all those who made these first steps successful. Firstly, the presenters at the conference and the contributors in this volume for sharing high-quality research results with the rest of the community. Also, the scientific committee who ensured the presentation and publication of work at international standards. Besides, the participants for attending the conference, and the sponsors who contributed to the smooth running of the event. We anticipate many more meetings and publications in the future.

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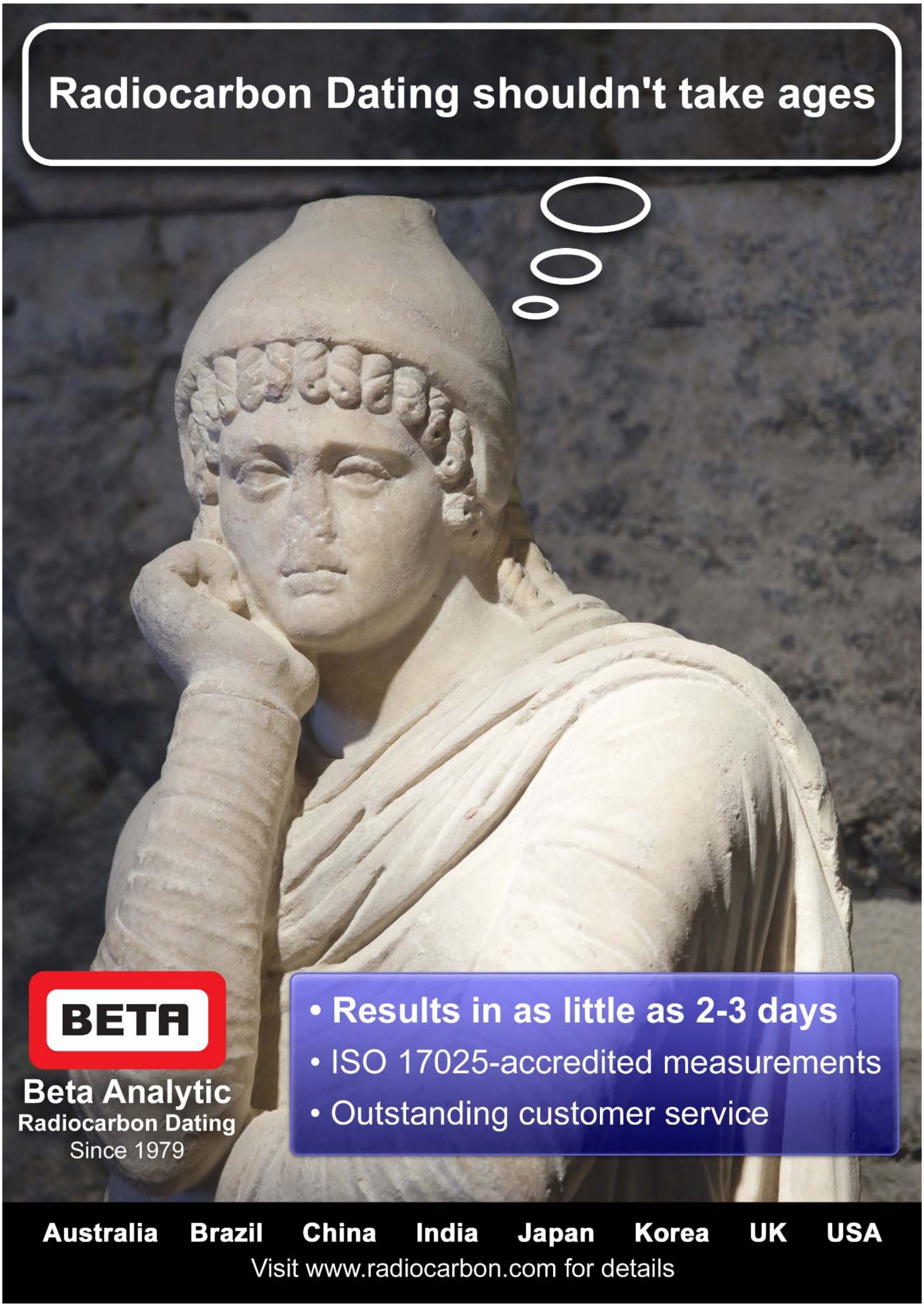

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TREKKING AND TRACKING - GIS AND MINOAN LAND USE: BETWEEN LANDSCAPE AND COMPUTER SCREEN

S. BECKMANN

University of Crete
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Περίληψη/ Abstract
Η τοπογραφική έρευνα της συγγραφέως στα βουνά νότια από τον Άγιο Νικόλαο, Κρήτη, οδήγησε στην ανακάλυψη άνω από 330 Μινωϊκές αγροτικές θέσεις, χρονολογημένες μέσω της επιφανειακής κεραμικής στην Μέση Εποχή του Χαλκού (2000–1700 π.Χ.). Με την βοήθεια εφαρμογών Συστημάτων Γεωγραφικών Πληροφοριών (GIS), τα ερείπια κατοικημένων θέσεων, οι περίβολοι και οι συνδετικοί δρόμοι χαρτογραφήθηκαν και η λειτουργία τους σαν αγροτικές εγκαταστάσεις μικτής γεωργοκτηνοτροφικής εκμετάλλευσης (συμπεριλαμβάνοντας βοσκή αιγοπροβάτων και μελισσοκομία), όσο και οι πιθανές χρήσεις γης μπόρεσαν να προσδιοριστούν. Το κείμενο αυτό θα δείξει τις μεθόδους και τα αποτελέσματα της παραπάνω μελέτης.

The author’s topographical research in the mountains above Agios Nikolaos, Crete, has led to the discovery of over 330 Minoan agricultural sites, datable by surface pottery to the Middle Bronze Age (2000–1700 BCE). With the help of GIS,habitation ruins, enclosure walls and connecting roads have been mapped, and their function as farming installations for mixed agriculture and animal husbandry (including herding of ovicaprids and bee keeping), as well as their possible land use potential could be determined. The paper is going to show the methods and results of this study.

*Keywords:*Minoan walls, Middle Bronze Age Cretan land use, Middle Minoan architecture in the mountains, GIS and Minoan land use.

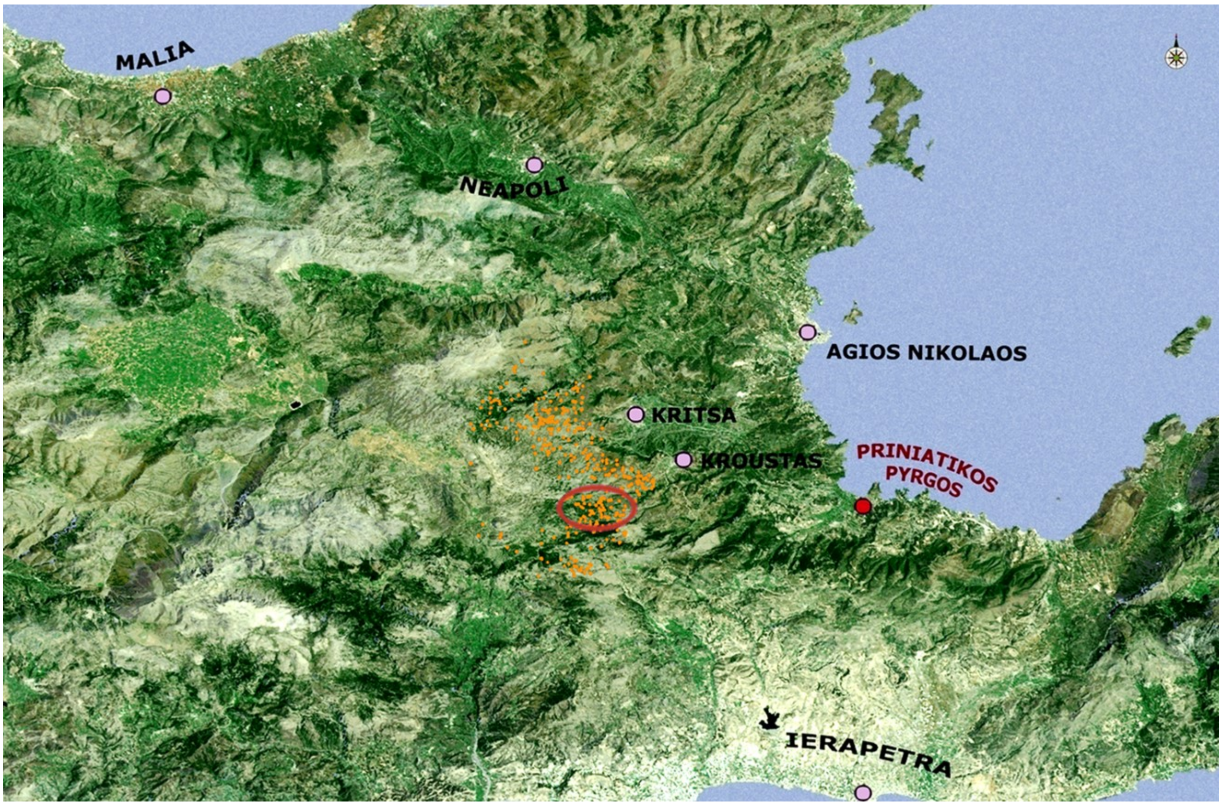

Figure 1 Map of the Agios Nikolaos area, Crete, with the study region west of Kritsa and Kroustas. The Kroustas Park area used as example region in this paper lies within the oval shape.

Introduction

In north-east Crete, on the mountainous slopes south of Agios Nikolaos, over 330 Middle Minoan (*c.*2000–1650 BCE) habitation sites built with massive block masonry were arranged isolated but on average not more than 300 mapart from each other. They were interconnected with a network of paths and surrounded by long enclosure-walls claiming areas of up to 6 hectares for each site, including arable and rocky land. The setting and massive construction of the enclosures, originally more than 1 meter high (total known length ca. 150 km), show that they belonged to the sites.Landscape opening and structuring of these massive installations cover an area of ca. 30 km^2, subject of the author's PhD thesis (Beckmann 2012b).

In this essay it shall be discussed how field walking and processing GIS data can shed a light on the function of the Minoan sites described, and possibilities of Middle Bronze Age land use in the north-east Cretan mountains shall be demonstrated.

While in the past prehistorians believed a few of the then known sites along the ancient roads between coast and high mountain plains (Katharo, Lasithi) to have been defensible installations because of their so-called 'monumental' or 'Cyclopean' masonry (Evans & Myres 1895 in Brown 2001, 204), the author suggests an agricultural function of the installations. Theoretical considerations leading to this concept were corroborated by extensive field walking and mapping of walls and paths defining the enclosures. The characteristic architecture of this prehistorical phase can be shown to have clear typological differences as compared to other phases and is suggested to be called *oncolithic* (from Greek 'onkolithos', massive block) from now on (Beckmann 2012a, 2012b - site numbers in this paper follow the numbering in Beckmann 2012b).

1. Methodology

Intensive survey methods characteristically employ transects where field walkers follow theoretical parallel lines on the map in search for (mostly moveable) artefacts to create a record of material culture for a given area. Studies follow mainly what Gkiasta (2008) calls a 'landscape tradition'. Still the datability of sites ('sites' are usually defined as focus of surface artefacts) is mostly based on characteristic small finds (usually pottery), so that the possible location of sites is often limited to settlement positions (habitation sites) where pottery traces can be found, especially for prehistoric sites. It follows that features with little related traceable pottery produce what Bintliff and Howard (1999) called a 'hidden prehistoric landscape'.

For lowland regions, where continuous ploughing and other land use have mostly destroyed any evidence for (often perishable) architecture, Bintliff's suggestions may be the only solution to achieve a better image of the conditions of prehistoric settlement.

In Crete, where 3/5 of the land is situated higher than 200 m on more or less steep and rocky slopes, karstic mountainous landscapes rarely preserve masking alluvial soils, so consequently in these areas the 'prehistoric hidden landscape' looks different:

While recent land use of mixed small scale agriculture with stress on animal husbandry hardly interferes with the visibility of ancient stone architecture (while it does re-use it), the often fearfully tiny amounts of pottery associated with prehistoric isolated vernacular sites seems to have made them quasi invisible to archaeologists, even though they sometimes are conspicuous. The situation is aggravated by the fact that the already small amount of moveable finds, wandering often far downslope, hiding in crevices and additionally in the process being reduced to no more than the most resilient material, makes the archaeological visibility – and datability – of sites even more difficult. Apart from the difficulties related to moveable finds, any survey approach using parallel transects is doomed in a landscape of intense profile and often man-high, dense, thorny phrygana, while structures like the traces of ancient walls snaking through it would be perpetually missed.

Thus a topographical research rather than an intensive survey of Gkiasta's 'landscape tradition', combined with detailed architectural analysis seemed the appropriate approach for the author's discovery and study of the sites (Beckmann 2012b, cf. Fig. 1 above).The unusual settlement pattern with over 330 dwelling sites (named thus to differentiate them from other wall remains of the area, cf. Beckmann 2012b, Ch II, 115) of the Middle Bronze Age in the mountains above Kritsa and Kroustas had first been discovered by the author (between 2003 and 2009, regularly reported to the archaeological service) during informal hikes. There it became obvious that the few massive ruins known to archaeologists until then (cf. for instance Evans & Myres 1895, Taramelli 1899, Zielinski 1998, Alusik 2007) and – following Evans - interpreted as military (or at least defense) installations, were only precious few of those extant (within 500 m distance) in the vicinity of the – obviously ancient - road between Kritsa and the highland plateau of Katharo (cf. Beckmann 2012b, Ch II b E, 158–164). It stands to reason that Evans and Myres probably never left the track of this road (they called it 'Mycenaean military road', Evans & Myres 1895) further than a few meters and hence missed other sites.

Interestingly the main area settled in the MBA lies between the two torrents draining winter rains from the mountain slopes into the *Kalos Potamos* river joining the sea next to the Minoan harbour settlement being excavated recently under the auspices of the Irish School of Hellenic Studies at 'Priniatikos Pyrgos' (cf. http://www.priniatikos.net) (Kalo Chorio, distance from study area ca. 7–8 km).One might speculate that there was a connection, but up to now no clear connections could be ascertained and any possible reasons for the extensive settlement and its apparently sudden demise ca. 300 years later must remain speculative (Beckmann 2012b).

Apart from the main study region on the north-eastern slopes overlooking the Mirabello bay, there is also a continuity in a second similarly settled area towards the south-west on the southern side of the watershed overlooking part of the south coast. Still habitation sites are situated only 600–700 m from those in the Kroustas forest area. As all the studied sites had similar architecture, were accompanied by similarly built enclosure walls and roads/paths, and could be dated to a similar time of use, the whole 'settlement system' was understood as a unit and analyzed as such (Beckmann 2012a, 2012b).

The ensuing study and recognition of characteristic architectural features of Minoan Middle Bronze Age settlement in the area, in combination with walking and plotting structures like dwelling ruins, enclosure walls and related roads, processed in GIS, made it possible to give an approach to studying Minoan installations and land use in the mountains above Agios Nikolaos in the first half of the second millennium BCE (Beckmann 2012a, 2012b). The study also included an extensive ethnographical part (Beckmann 2012b, Ch.Ib:27–84), as in pre-industrial levels of mountain life it is quite possible to detect analogies and differences with ancient land use. Human responses to similar environmental conditions remain comparable even without (as it seems to have been the case in this area) continuous tradition (cf. Cunningham 2009, 123–124).

The methodology and results of this study (the archaeological part), from a basic introduction to Minoan architectural patterns in wall building, the method of field walking and plotting prehistorical structures in the mountains, processing them digitally, to the possibilities of land use analysis can be summarized thus:

1. Several Minoan mountain habitation sites with a good collection of surface pottery provided a general dating that could be linked to definite architectural units (see below for typology). Comparing architectural patterns in the construction rather than the juxtaposition of walls showed that Middle Bronze Age building techniques were distinctive enough torecognize them even in the near absence of pottery. The related surrounding enclosure walls and road constructions proved to be the most useful discoveries for later land use analysis, attributing definite plots of land and characteristic connectibility to the enclosed habitations.

2. During field walking GPS tracks and waypoints were produced (geo-referencing), with which long Minoan walls were plotted onto digital maps as tracks. Combining these track lines, map images of the actual enclosed areas and connecting roads could

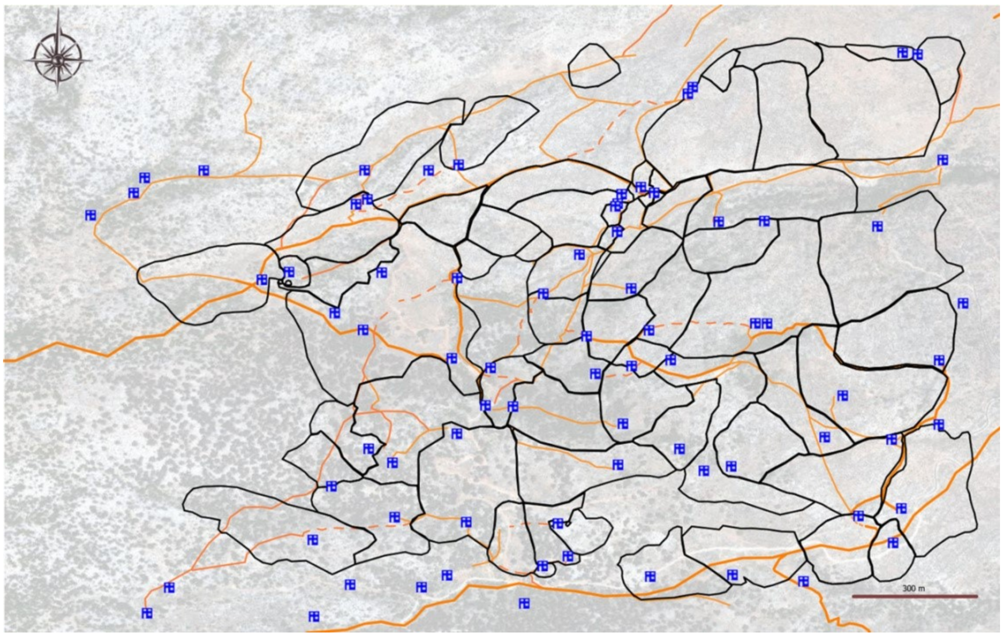

Figure 2 Middle Minoan structures in the area of Kroustas Historical Landscape Park including habitation sites (blue squares), enclosure walls (black lines) and connecting

be generated. Positions of buildings and other important features (round structures, water sources, caves etc.) were entered into the software (Ozi-Explorer, Global Mapper) as waypoints, showing, for instance, the fact that caves were also served by the Minoan road network (Fig. 2).

3. By digitally processing tracks and waypoints in GIS, distinct area features were generated, and in combination with evaluation of various landscape capacities, specifications of a region could be visualised (e.g. areas with good or medium good soil to determine arability- and other land use potential, see below Fig. 9).

Using the sizes of these various areas produced on the map, the possible amount and quality of arable land per habitation site within their enclosures could be determined, allowing an assessment of sustainability and often the approximate quantity (at least as a lower limit) of possible surplus that could be generated from the Bronze Age fields.

2. Typology of Minoan Middle Bronze Age vernacular architecture of the Agios Nikolaos area

'Oncolithic' blocks (minimum side of block: 35 cm, minimum second side 1,25 times that much) were always unworked and built without regular or isodomic courses. High massive walls are on downhill sides only, with no more than one or two courses on the uphill sides (indicating a clear difference to a fortification). Larger blocks were situated mostly in lower courses (as opposed to the architecture of Late Minoan big block walls usually constructed with a layer of rubble underneath). The walls were self-supporting, probably needing no mortar. Blocks did not come from quarries but from the surrounding surface (Fig. 3).

This typology also provides a clear distinction between this architecture and later Mycenaean building techniques and thus gives a tool to avoid confusion between oncolithic and 'Cyclopean' architecture for the Greek Bronze Age, suggesting to restrict the latter term to Mycenaean building styles as known from Tiryns, Mycenae etc. (cf. Shaw 1973, 80 and especially Küpper 1996, 31, Beckmann 2012b, Ch II b, 109–112)

Enclosure walls or *perivoloi* were built with masonry similar to the habitation ruins (the closer to those, the larger the used blocks). While in many cases there are only parts preserved, the whole shape can be detected in the region of over 200 habitations, in a total length of more than 150 km in the studied area.

Figure 3 Characteristic Minoan Middle Bronze Age habitation wall, Kroustas Park area.

3. Examples

While for instance in the Zakros region enclosure walls have been interpreted as fortification walls (following Evans' early misconception of what ruins with big stone architecture must have been mentioned above, cf. Tzedakis *et al.* 1989), the function of the Agios Nikolaos area's enclosure walls as agricultural can be understood when looking at their distribution and allocation relative to the dwelling sites, for example in the area of Kroustas Historical Landscape Park (about 4 km^2 of 30 studied all in all).

The park contains 77 Minoan habitation sites (20 of which stand at least in one part over 1,5 m high and have been declared as heritage protected).

When the areas within the enclosures are depicted as units and in different colours, it becomes obvious that most sites have clearly attributable shares of land. (Fig. 4).

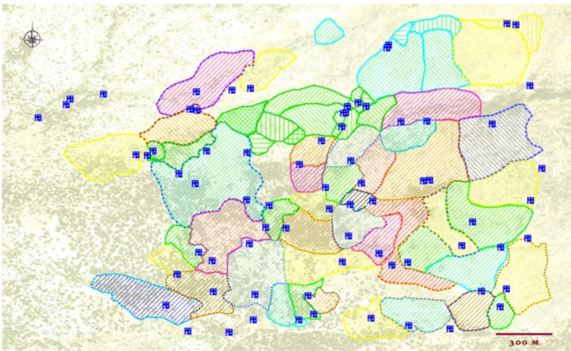

Figure 4 Habitation sites and their enclosures in the area of Kroustas Historical Landscape Park.

The most typical enclosures are of the 'individual *perivolos*' kind: one site enclosed by one surrounding *perivolos* ('Outer Perivolos'), as are most sites with traceable enclosures. Walls of several hundreds of meters length surround a larger area around the habitation sites, while close to the dwelling often exist extra sets of walling called the 'Inner Perivolos' as in most cases it lies within the outer one (Fig. 5).

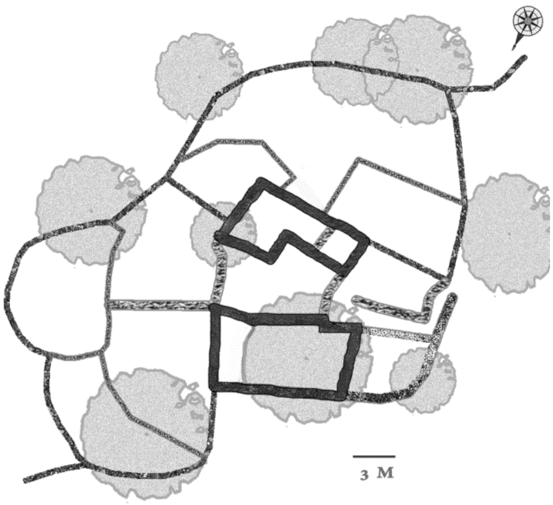

Figure 4 Topographical plan of Site 128 (Kroustas Park) showing the various small walled compartments within the Inner Perivolos (Outer Perivolos walls continuing to south and north) also containing two habitation ruins (bold lines).

The second case – called 'Shared Perivolos' - occurs only a few times in the study area. Here several individual and clearly separate dwellings, usually each surrounded by their own Inner Perivolos, share one big Outer Perivolos (Fig. 6). A variety of this can be seen in the top right corner of Figure 6: 2 habitations in separate Inner Perivoloi, adjoining one large shared Perivolos (all yellow in the figure).

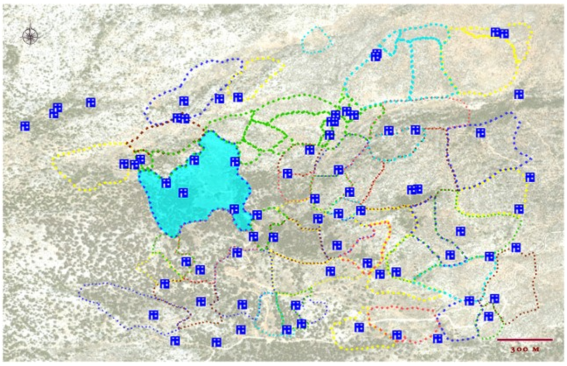

Figure 5 Shared Perivolos (containing 5 habitation sites) in the region of Kroustas Park.

The third case –'Shared individual Perivoloi' - features several dwellings close to each other (distance around 50–80 m), each within their own Inner Perivolos, but surrounded by a number of different enclosures. In this case a final attribution enclosure by site (which *perivolos* to which site) obviously cannot be done (Fig. 7).

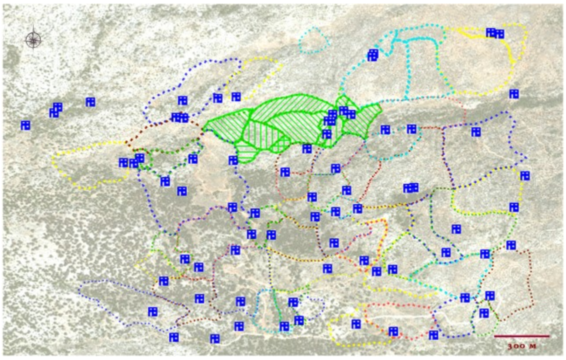

Figure 6 Shared individual *perivoloi* in the area of Kroustas Historical Landscape Park (Sites 99).

By the topographical position round structures (i.e. granaries and cisterns, cf. Strasser 1997) have within enclosures they can also be attributed to individual sites, introducing the subject of storage and respectively land use in the region (Fig. 8). Naturally in the case of the round structures the record is most probably incomplete as both kinds might easily become invisible to the modern eye.

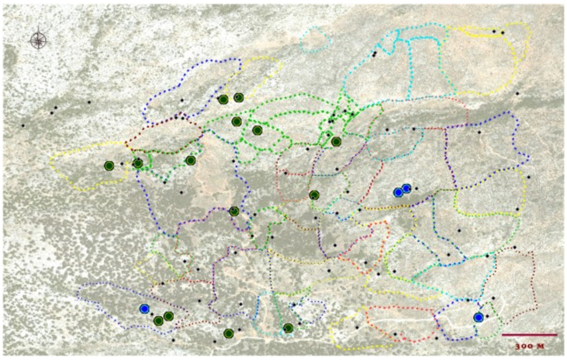

Figure 7 Middle Minoan habitations (black dots) and round structures in the area of Kroustas Historical Landscape Park: green 'granaries' (rubble round structures), blue 'cisterns' (oncolithic round structures).

While Minoan landscape structures have been slightly masked during the last 150 years of re-occupation by mixed agriculture, and there hardly exist any other traces of the phases between then and now, recent land use often employed the ancient remains. To avoid any possibilities of confusion with modern structures the following example is taken from the number of many sites seemingly not reoccupied over the last 4000 years.

4. Land-Use – example Site 189

The Middle Minoan site 189 (Beckmann 2012b, 459) in the region of Kroustas Historical Landscape Park, with habitation, walls, round structures and arable land (of varyingquality in different areas) within its enclosure, was one of many sites (ibid., passim) plotted onto digital maps, using the software *OZI*

Explorer and *Global Mapper* (Fig. 9). Thus a set of data could be produced to evaluate the site's land use possibilities.

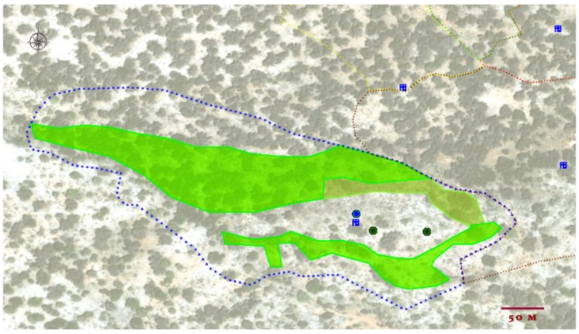

Figure 8 Site 189 (habitation at blue circle) with its round structures (2 granary-type, green, 1 cistern-type, blue) within its enclosure containing good fields (intense green) and medium fields (khaki). Situated in the Kroustas Historical Landscape Park area (position on maps above bottom left).

Data:

- Outer Perivolos: 6.4 ha area, length 1200 m. (Inner Perivolos around 1000 m^2, not accounted for in this example).
- Good fields: ca. 2 ha. ('Good fields': Less than 15% rocks – mostly alluvial/colluvial).
- Medium fields: 0.3 ha. ('Medium fields': Less than 60% rocks – often terraced, here counted with factor ½ of the good ones in possible production).
- Wasteland: 4.1 ha. ('Wasteland': More than 60% rocks, mostly not cultivable, often acceptable for browsing).
- 1 ha. of Greek field (no fertilizers and irrigation, Ilios 1941–'52) can produce ca 80–260 kg barley/year, i.e. for site 189: 1600 to 5200 kg (The lower amount could be corroborated by a trial field of 100 m^2cultivated in the area by the author. The trial consisted ofsowing and reaping,while the field was protected from browsing animals, no further manipulation of any kind.
- Average need of inhabitants: 128 kg of cereals per person/year (i.e. 640 kg for a family of 5).

Given the field sizes, pre-industrial production methods and the known amounts of cereals that can be grown on Greek fields, a calculation for this site returns that it could have produced up to 4.500 kg/year (ca. 8 $m^3$of surplus). This obviously provides a good reason for the existence of two granaries with (estimated on the basis of known comparable granaries elsewhere in the eastern Mediterranean Bronze Age) ca. 5–8 cubic meters each.

But agriculture constitutes only part of the land use possibilities (and necessities) in this region, another important part being animal husbandry. For managing animals walling/fencing is needed. In the Cretan mountains there have always been sheep and goats (Chaniotis 1996), and with them always a need for protecting fields from them. That is one obvious function of enclosure walls. Recent mixed farming let animals browse outside of fenced, cultivated areas during the winter and (for a short time per day) within the fences after the harvest, often with the straw remaining on the fields for that reason. But there are more specific uses of walling recognizable by comparison with recent structures.

One known type of walled structures for pre-industrial animal husbandry in the area is milking pens. They are always built in an ellipsoid shape without corners to keep animals from getting caught in them during milking the herd, which takes place at the entrance (usually on a small side) while sheep by sheep passes the milker to leave the pen.

Thus by comparison possible Minoan milking pens may be recognizable in the study area (Fig. 10, 11).

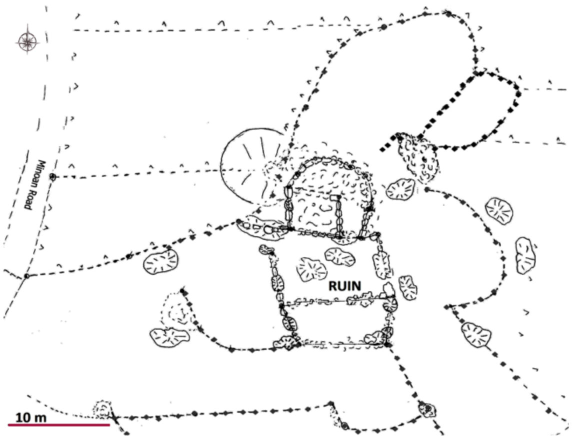

Figure 9 Drawing of habitation Site 53, including surrounding walls. Note the typical oval shape with opening on one small side that looks like a milking pen, top right.

Conclusions

With the help of finds from the Agios Nikolaos Mountains, and provided GIS data is treated with care and knowledge of this landscape's potentialities, Cretan Middle Bronze Age land use can now be traced by studying the region's ancient agricultural walling.

Figure 10 Possible Minoan milking pen. The typical rounded shape runs along the edge of the photo, the enclosure is situated next to a rectangular dwelling ruin (in the background behind the trees, the girl stands on the upper corner). Kroustas Historical Landscape Park (Site 174) Photo: Johnny Ivanovas.

The region of Kroustas Forest Historical Landscape Park (http://kroustas-park.gr), developed since 2012 by the author and the cultural club of Kroustas (under supervision of the local archaeological service), features hiking paths along which many of the best preserved Bronze Age ruins – still unexcavated so far – can be visited. The forested slopes of the park offer their appeal not only to archaeologists coming to study the Middle Bronze Age settlement, but also to tourists visiting the Minoan hinterland installations and their forest landscape out of general cultural interest.

Depending on future funding, cleaning of ruins and possibly some excavations might be conducted by the Greek archaeological service. Historical shepherd and agricultural installations of the Cretan pre-industrial phase can be visited as well. Areconstruction of a Minoan farmbuilt from scratch based on archaeological evidence from the area's Bronze Age ruins (and other Cretan remains, for instance from Malia's Quartier Mu for the unbaked plinths of the upper structures) is planned to show visitors how a Minoan farm would have looked like (and what it might have contained, may be even how it functioned) while it was in use. Hopefully the financial crisis can be overcome in part to realize these plans within the next few years.

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ΕΦΑΡΜΟΣΜΕΝΗ ΓΕΩΠΛΗΡΟΦΟΡΙΚΗ ΚΑΙ ΓΕΩΟΠΤΙΚΟΠΟΙΣΗ ΣΤΗΝ ΑΡΧΑΙΟΛΟΓΙΑ. ΜΕΛΕΤΗ ΤΗΣ ΠΟΡΕΙΑΣ ΤΟΥ ΡΩΜΑΪΚΟΥ ΥΔΡΑΓΩΓΕΙΟΥ ΜΥΤΙΛΗΝΗΣ

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Περίληψη/ Abstract

Το ρωμαϊκό υδραγωγείο Μυτιλήνης αποτελεί ένα από τα σημαντικότερα τεχνικά έργα της αρχαιότητας στο νησιωτικό χώρο, το οποίο όμως έχει μελετηθεί ελάχιστα. Η κατασκευή του αποσκοπούσε στην κάλυψη των υδρευτικών αναγκών της πόλεως της Μυτιλήνης κατά τους πρώτους μεταχριστιανικούς αιώνες. Η πορεία του ξεκινάει από τις πηγές του όρους Όλυμπος, στο κεντρικό τμήμα του νησιού, και καταλήγει στη Μυτιλήνη (περιοχή αρχαίου Θεάτρου) διασχίζοντας ένα έντονο γεωμορφολογικά ανάγλυφο (με πορεία μήκους 43 περίπου χιλιομέτρων). Στο άρθρο αυτό παρουσιάζονται τα αποτελέσματα της προκαταρκτικής μελέτης ανακάλυψης, χαρτογράφησης και οπτικοποίησης της χωρικής δομής του υδραγωγείου και του γεωμορφολογικού ανάγλυφου μέσα από το οποίο αυτό διέρχεται. Με τη χρήση εργαλείων γεωπληροφορικής, δεδομένων μικρής και μεσαίας χωρικής κλίμακας, υπολογίζεται η πορεία του υδραγωγείου στην αρχαιότητα. Ο υπολογισμός, εκτός από τη χωρική ανάλυση, στηρίζεται σε νέα επιτόπια έρευνα και μελέτη των σωζόμενων τμημάτων του τεχνικού αυτού έργου (υδατογέφυρες, υπόγειοι και λαξευτοί αγωγοί μεταφοράς υδάτων κ.α.).

The Roman aqueduct of Mytilene is one of the greatest technical works of antiquity in the Aegean, but it has been little studied. Its construction was intended to provide water for the city of Mytilene in the early Christian period. It begins on the slopes of Olympus in the central part of the island and reaches the city of Mytilene at the east coast (the area of the ancient Theater) stretching across varied geomorphological terrain, (having in total around 43 kilometers of length). This paper presents results of the preliminary study of the mapping, understanding and conceptualizing of the structure of the aqueduct and that of its geomorphological terrain. Using GIS, we have collected and analyzed data on a small and medium- spatial scale, calculating the way that the aqueduct had in antiquity. The calculation in addition to and apart from this spatial resolution will incorporate knowledge of the existing sections, including water bridges and both above and underground water channels.

Λέξεις Κλειδιά: Γεωπληροφορική, Χαρτογραφική Απεικόνιση, Χωρική Ανάλυση, Ρωμαϊκό Υδραγωγείο, Λέσβος

Εισαγωγή

Αντικείμενο της παρούσας μελέτης είναι το αρχαίο υδραγωγείο της Μυτιλήνης, ένα σημαντικό τεχνικό έργο, το οποίο έχει μελετηθεί ελάχιστα έως σήμερα.
Η σπουδαιότερη έρευνα για το υδραγωγείο πραγματοποιήθηκε στα τέλη του 19ου αι. από τον R. Koldewey, ο οποίος αποτύπωσε αρχιτεκτονικά τις περισσότερες υδατογέφυρές του και ασχολήθηκε συνοπτικά με το θέμα της πορείας του και της μορφής των λαξευτών καναλιών (Koldewey 1890, 65–68, πίνακας 29). Η εργασία του παραμένει μέχρι και σήμερα ένας πολύτιμος οδηγός για μία πιο εμπεριστατωμένη μελέτη του μνημείου. Από τους Έλληνες ερευνητές, που έχουν ασχοληθεί με το αρχαίο υδραγωγείο, σημαντικότερες κρίνονται οι μελέτες του αρχαιολόγου Ιωάννη Κοντή και του μηχανικού Ιωάννη Χατζηϊωάννου (Κοντής 1973α, 77–81, Κοντής 1973β, 117–122, Χατζηϊωάννου 1985, 153-162).

Η Μυτιλήνη στους ρωμαϊκούς χρόνους αποτέλεσε, σύμφωνα με τις μαρτυρίες των συγγραφέων και τα αρχαιολογικών ευρημάτων, μία λαμπρή πόλη, το ίδιο όμορφη όπως η Ρόδος και η Έφεσος (Labarre 1996, 69–156, Κοντής 1978, 197–201). Ένα σύνθετο σύστημα μεταφοράς υδάτων κατασκευάστηκε για την κάλυψη των αυξημένων υδρευτικών αναγκών στην εποχή του μηχανικού Αγρίππα, γαμπρού του Αυγούστου, (Χατζηϊωάννου 1985, 156), κατά την πρώτη εκδοχή, ή στην εποχή του Αδριανού στα μέσα του 2ου αι. μ.Χ., κατά την επικρατέστερη άποψη (Κοντής 1973α, 77-81). Το έργο μετέφερε το νερό των πηγών του ορεινού όγκου του Ολύμπου στην ανατολική πλευρά του νησιού, όπου ήταν χτισμένη η πόλη της Μυτιλήνης (Koldewey 1890, 65). Για τους αρχαίους μηχανικούς η κύρια μέριμνα ήταν η μεταφορά της καλύτερης ποιότητας νερού, ανεξαρτήτως απόστασης (Mays 2010, 117) και η διατήρηση της σωστής κλίσης ροής του νερού με τη βοήθεια τεχνικών λύσεων εξομάλυνσης των διακυμάνσεων του εδαφικού αναγλύφου, όπως οι κτιστοί ή λαξευτοί θολωτοί αγωγοί, υπόγειοι ή υπέργειοι, οι δεξαμενές, οι υδατογέφυρες κ.α. (Hodge 1992, 126–170). Για μεγάλα τεχνικά έργα της αρχαιότητας, όπως τα υδραγωγεία, το εδαφικό ανάγλυφο της περιοχής διέλευσης καθόριζε σε μεγάλο βαθμό και τον τρόπο κατασκευής τους (Καϊάφα 2008, 29, σημ. 41).

Τα Γεωγραφικά Συστήματα Πληροφοριών (Γ.Σ.Π), ιδιαίτερα στο εξωτερικό, θεωρούνται πλέον αναπόσπαστο κομμάτι της επιστήμης της αρχαιολογίας και της μελέτης αρχαιολογικών μνημείων συνδεδεμένων με ένα γεωγραφικό ανάγλυφο μικρής ή μεσαίας κλίμακας, καθώς αναδεικνύουν τη σχέση των αρχαίων δημιουργημάτων με το φυσικό τους περιβάλλον, το γεωγραφικό ανάγλυφο και τη φυσική ή τεχνητή διαμόρφωση του εδάφους (Romano *et al.* 2002, Georgoula *et al.* 2003).

Η χρήση των Γ.Σ.Π. στις αναλύσεις τοπίων είναι στην πρώτη γραμμή των εφαρμογών που υποστηρίζουν την αρχαιολογική έρευνα (Romano *et al.* 2002, Indruszewski 2003, Beex 2003). Η χαρτογράφηση των περιοχών μελέτης με τη δημιουργία πολυεπίπεδων χωρικών δεδομένων και κατάλληλων οπτικοποιήσεων μπορεί να εμφανίσει την πολυπλοκότητα της χωρικής πληροφορίας με σύγχρονο και κατανοητό τρόπο (Mardy & Rakos 1996). Η γεωγραφική οπτικοποίηση μπορεί να οδηγήσει σε νέες προσεγγίσεις με την παρουσίαση του γεωγραφικού χώρου, καθώς και των χρονικά μεταβαλλόμενων φαινομένων, που λαμβάνουν χώρα σε αυτόν (Duke 2002, Ortengo & Miro 2011).

Στο πλαίσιο της παρούσης μελέτης η επιτόπια έρευνα πιλοτικά εστιάστηκε στη χαρτογράφηση της μισής περίπου διαδρομής, ξεκινώντας από τη θέση «Λαρισαίες Πέτρες» έως και το κτιστό αγωγό που διέρχεται από το γνωστό ρωμαϊκό λατομείο στο «Κακό Λαγκάδι» Μόριας (Millar & Williams 1993, 211–224). Με αυτό τον τρόπο ερευνήθηκε περιοχή μήκους περίπου 20 χιλιομέτρων από τα περίπου 43 χλμ. της συνολικής διαδρομής. Η μελέτη ενός τμήματος του υδραγωγείου είχε ως στόχο την εύρεση της κατάλληλης μεθοδολογίας εκμετάλλευσης των αναλυτικών δυνατοτήτων των Γ.Σ.Π. σε χωρικά δεδομένα μικρής χωρικής κλίμακας.

Η αναγνώριση και ο καθορισμός της πορείας ενός υδρευτικού έργου με επιτόπια έρευνα αποτελεί εξαιρετικά επίπονη διαδικασία, καθώς οι μελετητές σε πολλές περιπτώσεις αντιμετωπίζουν απροσπέλαστες από την άγρια βλάστηση διαδρομές, χείμαρρους και επικίνδυνες αναβάσεις σε κάθετους βράχους. Επίσης, δυσκολίες της έρευνας αποτελούν οι καταστροφές και οι ανθρωπογενείς αλλοιώσεις και αλλαγές στο ανάγλυφο της περιοχής διέλευσης. Τέτοια είναι η περίπτωση σύγχρονου λατομείου αδρανών υλικών, το οποίο «εξαφάνισε» τμήμα του λαξευτού αγωγού σε μήκος περίπου 400 μ. Η λειτουργία του διεκόπη μόλις το 1991 με απόφαση του Υπουργείου Πολιτισμού.

1. Η οριοθέτηση της περιοχής έρευνας

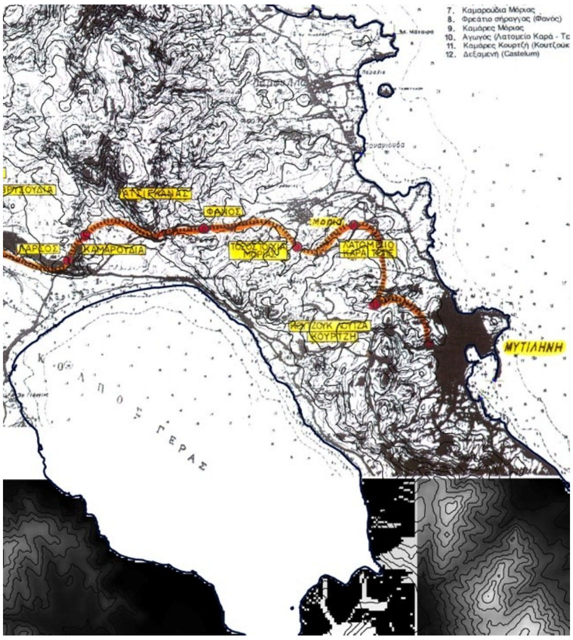
Η οριοθέτηση της περιοχής έρευνας έγινε έχοντας ως βάση τη συνοπτική μελέτη ενός ντόπιου μηχανικού, του Ι. Χατζηϊωάννου, ο οποίος το 1985 πάνω σε έναν αυτοσχέδιο χάρτη χάραξε «πρόχειρα» μία διαδρομή (Εικ. 1).

Εικόνα 1 Χάρτης του Ι. Χατζηϊωάννου (1985) με την «πρόχειρη» χάραξη της διαδρομής του υδραγωγείου.

Η τοπική Αρχαιολογική Υπηρεσία, αν και έχει κηρύξει ως αρχαιολογικούς χώρους τρία τμήματα του Υδραγωγείου ήδη από το 1991, διαθέτει συντεταγμένες για την περιοχή κήρυξης, αλλά όχι για τα ίδια τα κατάλοιπα και σε προσαρμογή που είχε κάνει σε χάρτη της Γ.Υ.Σ. κλίμακας 1:5000 μετέφερε κατά προσέγγιση την πορεία με βάση την άποψη του προαναφερθέντος μηχανικού (Εικ. 2).

Η Αρχαιολογική Υπηρεσία κατά συνέπεια δεν είχε λεπτομερή καταγραφή των σημείων του υδραγωγείου, παρά μόνον τις ζώνες προστασίας (Ζώνη Α και Β) των ορατών τμημάτων του.

Έτσι, λόγω της έλλειψης στοιχείων και χωρικής πληροφορίας σχεδόν για το σύνολο του υδραγωγείου, επιλέχθηκε η μελέτη στο πιλοτικό της στάδιο να περιοριστεί σε ένα τμήμα του. Με αυτό τον τρόπο τα συμπεράσματα της μελέτης αυτής θα αποτελέσουν οδηγό για την ανακάλυψη του συνόλου των σημείων του.



Εικόνα 2 Σημεία του υδραγωγείου και ο χάρτης της αρχαιολογικής υπηρεσίας με γεωαναφορά σύμφωνα με σύγχρονα χαρτογραφικά υπόβαθρα. Με πορτοκαλί χρώμα σημειώνεται η προτεινόμενη πορεία του υδραγωγείου.

2. Επιλεκτική Έρευνα Πεδίου

Η έλλειψη στοιχείων και χωρικής πληροφορίας για πολλά από τα σημεία της διαδρομής του υδραγωγείου οδήγησε στην επιλεκτική έρευνα πεδίου.

Κατά τη διάρκειά της έγιναν πολλές επισκέψεις στην περιοχή ενδιαφέροντος, όπου με τη χρήση GPS χειρός και ψηφιακής φωτογραφικής μηχανής, προσδιορίσθηκαν χωρικά οι συντεταγμένες όλων των θέσεων υψηλού ενδιαφέροντος, ενώ πρόσθετα αποτυπώθηκαν φωτογραφικά τα κατάλοιπα του υδραγωγείου. Ακολούθησε επεξεργασία των δεδομένων πεδίου, η οποία είχε ως στόχο την κατανόηση των αρχικών πληροφοριών της αρχαιολογικής έρευνας και την οριστικοποίηση της περιοχής μελέτης.

Ως προς την πορεία του υδραγωγείου, αρχικά χαρτογραφήθηκε ο υδραγωγικός καμαροσκεπής αγωγός, που εντοπίζεται λαξευμένος στον σχεδόν κάθετο βράχο του ασβεστολιθικού όγκου «Λαρισαίες Πέτρες» με προσανατολισμό Α-Δ. Το πλάτος του είναι 0,60 μ. ενώ το ύψος του με τη θολωτή επίστεψη διαμορφώνεται στα 1,15 μ. (Εικ. 3).

Εικόνα 3 Ο αγωγός στη θέση «Λαρισαίες Πέτρες».

Επόμενο σωζόμενο σημείο που ερευνήθηκε είναι η υδατογέφυρα στη θέση «Καμαρούδια», η οποία έχει προσανατολισμό ΒΔ-ΝΑ, πλάτος 2,15 με 2,10 μ. και πλάτος αγωγού επίσης 0,60 μ. (Εικ. 4).

Εικόνα 4 Υδατογέφυρα στην περιοχή «Καμαρούδια».

Το επόμενο σημείο επιτόπιας μελέτης αποτέλεσε ο κτιστός αγωγός, που αποκαλύφθηκε ανασκαφικά (Εικ. 5). Το νέο τμήμα του αγωγού, μήκους 54 μ., παρουσιάζει τα ίδια κατασκευαστικά στοιχεία, με άλλα γνωστά του τμήματα, ενώ ενδιαφέρον έχει η κλίση του, καθώς το ανώτερο σημείο του βρίσκεται στα 60,31 μ. ενώ το κατώτερο σε υψόμετρο 60,16 μ. Αποκαλύπτονται έτσι οι αμελητέες κλίσεις που απαιτούνται για την ομαλή κίνηση του νερού.

Στη συνέχεια καταγράφηκε ο λαξευμένος αγωγός στη θέση «Ατσιγκάνα», από όπου ο αγωγός γινόταν υπόγειος μέσω σήραγγας, όπως αυτής του Ευπαλίνειου ορύγματος στη Σάμο. Σε απόσταση 180 μ. ανατολικά η ανασκαφική έρευνα ενός κάθετου χτιστού, τετράγωνης διατομής φρεατίου (Εικ. 6), εξωτερικών διαστάσεων 2,54Χ2,24 μ. (*Φανός* ή *qanat*) μας παρέχει ιδιαίτερα σημαντικά στοιχεία για την πορεία του έργου (Καϊάφα 2008, 68-69, σημ.54).

Εικόνα 5 Τμήμα του λιθόκτιστου αγωγού του υδραγωγείου, το οποίο έχει αποκαλυφθεί πρόσφατα.

Εικόνα 6 Το κτιστό κάθετο φρεάτιο που αποκαλύφθηκε πρόσφατα. (*Φανός* ή *qanat*).

Ο Φανός αποκαλύφθηκε σε υψόμετρο 95,268 μ., το οποίο σημαίνει ότι για να επιτευχθεί ομαλή κλίση στον αγωγό, σε σχέση με το προηγούμενο ορατό σημείο (60,16 μ.), το συνολικό ύψος του φρεατίου πρέπει να είναι τουλάχιστον 35,108 μ. Στη συνέχεια ο αγωγός συνεχίζει την πορεία του υπόγειος έως ότου φτάσει στην περιοχή της Μόριας. Εκεί συναντά την ομώνυμη υδατογέφυρα μήκους 170 μ., μέγιστου ύψους 26 μ. στο κέντρο της κοιλάδας (Εικ. 7). Η υδατογέφυρα αποτελείται από 17 πεσσούς και 3 επάλληλες σειρές τόξων καθ' ύψος και αποτελεί το σημαντικότερο τμήμα του ρωμαϊκού υδραγωγείου, και ίσως το κορυφαίο μνημείο της λεσβιακής υπαίθρου (Κοντής 1973α, Koldewey 1890, 66–67, πιν. 29.1).

Ο αγωγός διέρχεται στην κορυφή της υδατογέφυρας για να συνεχίσει την πορεία του προς τα ανατολικά προς το ρωμαϊκό λατομείο στο «Κακό Λαγκάδι». Εκεί ο αγωγός είναι ορατός σε μήκος πάνω από 100 μ. με πορεία Α-Δ.

Εικόνα 7 Η γνωστότερη τοξοστοιχία/υδατογέφυρα του υδραγωγείου στην περιοχή Μόρια.

Η καταγραφή της υψομετρικής διαφοράς από το αρχικό σημείο της μελέτης μας στη θέση «Λαρισαίες Πέτρες» με υψόμετρο πυθμένα αγωγού 76 μ. από τη θάλασσα έως τον αγωγό στην περιοχή «Κακό Λαγκάδι» με υψόμετρο πυθμένα αγωγού 52,3 μ., αν και λήφθηκε με GPS χειρός (με ακρίβεια αναφοράς θέσης 2–3 μέτρα), είναι ενδεικτική των κλίσεων που απαιτούνταν για την ομαλή ροή του νερού.

Στην παρούσα μελέτη δεν συμπεριλήφθηκε η δίτοξη υδατογέφυρα στην περιοχή «Θερμές Πηγές Κουρτζή», η οποία είναι το τελευταίο ορατό τμήμα του υδραγωγείου πριν την είσοδο του αγωγού στην πόλη. Το τέρμα της διαδρομής του υδραγωγείου υπολογίζεται ότι βρίσκεται εντός των τειχών στην περιοχή κάτω από τον «Τεκέ» του αρχαίου θεάτρου, σε υψόμετρο περίπου 35 μ. από την επιφάνεια της θάλασσας (Χατζηϊωάννου 1985), αν και απαιτείται περαιτέρω έρευνα για τη διαπίστωση της θέσης της δεξαμενής συγκέντρωσης και διανομής του νερού (castellum).

3. Μεθοδολογία

Για τη διαχείριση και ερμηνεία των καταλοίπων των κατασκευών του έργου σε συνάρτηση με το ανάγλυφο της γύρω περιοχής κατασκευάστηκε, με τη χρήση ενός Γ.Σ.Π., μία χωρική βάση δεδομένων, στην οποία εισήχθηκαν όλα τα στοιχεία της έρευνας, τα οποία αποτελούν:

- σύγχρονοι τοπογραφικοί χάρτες κλίμακας 1:50.000 και 1:5.000, με ακρίβεια 12,5m και 1,25m αντίστοιχα, της Γεωγραφικής Υπηρεσίας Στρατού,
- ψηφιακοί χάρτες,
- αεροφωτογραφίες 1:2.500 από το Ελληνικό Κτηματολόγιο ακρίβειας μικρότερης ή ίσης του ενός μέτρου,
- δεδομένα επιφανειακής έρευνας, καθώς και
- διανυσματικά δεδομένα ανασκαφών της περιοχής που έχουν γεωαναφερθεί.

Οι αναλογικοί χάρτες της αρχαιολογικής υπηρεσίας ψηφιοποιήθηκαν και γεωαναφέρθηκαν στο Ελληνικό

Γεωδαιτικό Σύστημα Αναφοράς του 1987, εξασφαλίζοντας έτσι την ταύτισή τους, αλλά κυρίως την σύγκρισή τους με τα σύγχρονα χαρτογραφικά υπόβαθρα.

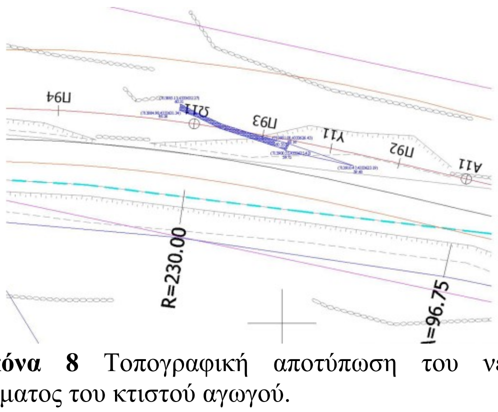
Πρόσθετα για την μελέτη της πορείας του υδραγωγείου χρησιμοποιήθηκαν:

1. ψηφιακό μοντέλο εδάφους DEM ανάλυσης 30x30 m
2. Διανυσματικά αρχεία για
    α. την ακτογραμμή
    β. το οδικό δίκτυο
    γ. το υδρογραφικό δίκτυο
3. καθώς και σημεία GPS που ανακτήθηκαν από την επιλεκτική έρευνα πεδίου.

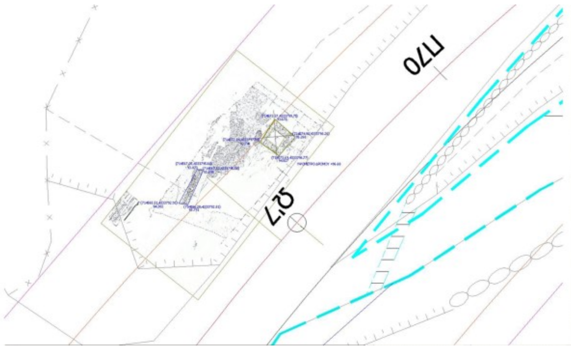
Χαρτογραφικά υπόβαθρα του Εργαστηρίου Χαρτογραφίας και Γεωπληροφορικής του Τμήματος Γεωγραφίας του Πανεπιστημίου Αιγαίου χρησιμοποιήθηκαν για την εύρεση σημείων ελέγχου στο έδαφος και την υλοποίηση της Γεωαναφοράς των αναλογικών χαρτών της αρχαιολογικής υπηρεσίας. Τέλος, τα σημεία που ανακτήθηκαν από την επιλεκτική έρευνα πεδίου χρησιμοποιήθηκαν για τη χωρική τοποθέτηση και ταύτιση των εναπομεινάντων καταλοίπων του υδραγωγείου στο ανάγλυφο.

Με αυτό τον τρόπο οι θέσεις του υδραγωγείου ενσωματώθηκαν στο Γ.Σ.Π., με αποτέλεσμα οι εντοπισμένες αρχαιολογικές θέσεις να είναι πλήρως και με απόλυτη ακρίβεια καθορισμένες στο χώρο (Εικ. 8–9). Ευτυχή συγκυρία για τη μελέτη αποτέλεσε η ανασκαφική έρευνα που διεξάγεται για πρώτη φορά σε κατάλοιπα του υδραγωγείου, στο πλαίσιο του έργου της 36ης Εθνικής Οδού. Κατά τη διάρκεια των εργασιών της, αποκαλύφθηκε κτιστός αγωγός του υδραγωγείου σε μήκος 54 μ. (έως 26 Απριλίου 2014) μαζί με το κάθετο φρέαρ (*Φανός*).

Τα νέα αυτά στοιχεία της ανασκαφικής έρευνας ενσωματώθηκαν στην γεωβάση, παρέχοντας μεγαλύτερη ακρίβεια στις υπάρχουσες μετρήσεις.



Εικόνα 8 Τοπογραφική αποτύπωση του νέου τμήματος του κτιστού αγωγού.



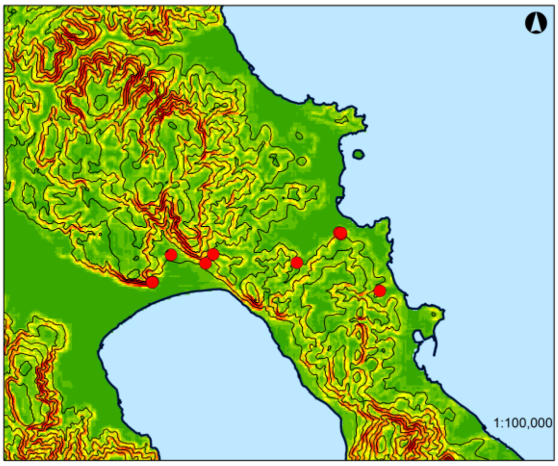
Εικόνα 9 Τοπογραφική αποτύπωση του Φανού από την εν εξελίξει αρχαιολογική ανασκαφή.

3α. Ανάλυση πορείας

Η μέθοδος ανάλυσης ελαχίστου κόστους διαδρομής (Least Cost Route Analysis) χρησιμοποιήθηκε για την εύρεση των περιοχών από τις οποίες θα μπορούσε να διέρχεται ο αγωγός του υδραγωγείου.
Η μεθοδολογία αυτή έχει χρησιμοποιηθεί στο παρελθόν για την εύρεση βέλτιστων θέσεων και διαδρομών υδραγωγείων (Leusen 1999, Gietl *et al.* 2008, Ortengo & Miro 2011).

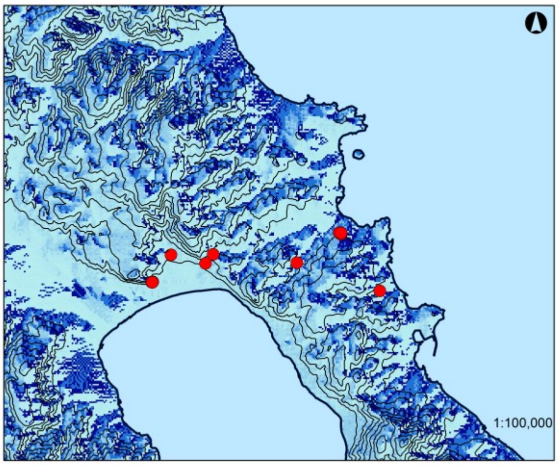
Για τη μελέτη των στοιχείων που συλλέχθηκαν δημιουργήθηκαν οι παρακάτω χάρτες:

1. Χάρτης Κλίσεων της περιοχής μελέτης (Slope maps) με διαβάθμιση ανά 2 μοίρες (Εικ. 10).



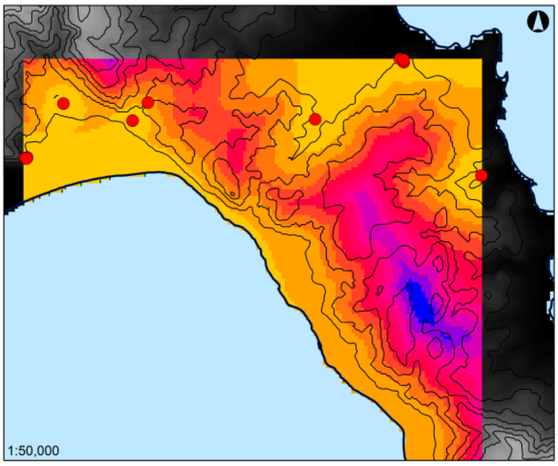
Εικόνα 10 Χάρτης κλίσεων της περιοχής μελέτης. Με κόκκινο αποδίδονται τα σημεία του υδραγωγείου που βρίσκονται σε περιοχές με πολύ μικρή κλίση (κλίσεις μεταξύ 0,1 και 2 %).

2. Χάρτες κατεύθυνσης της ροής (Flow direction maps). Οι χάρτες αυτοί απεικονίζουν τα ράστερ δεδομένα, τα οποία παρήχθησαν για την απεικόνιση της κατεύθυνσης της φυσικής ροής μέσα στο ανάγλυφο για κάθε κελί του ψηφιακού μοντέλου εδάφους στα γειτονικά του (Εικ. 11).



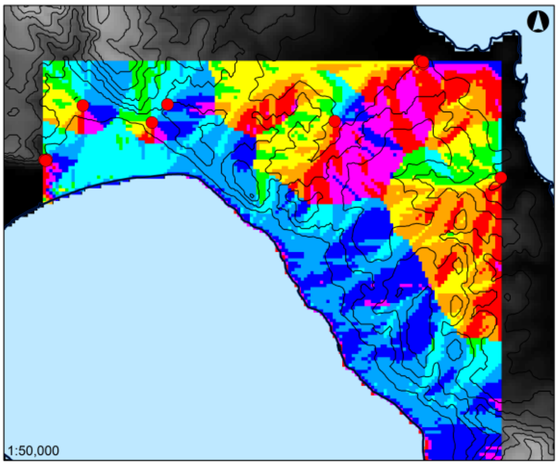
Εικόνα 11 Αποτελέσματα κατεύθυνσης ροής της περιοχής μελέτης. Με σκούρο χρώμα αποδίδονται σημεία του ανάγλυφου στα οποία η φυσική ροή του νερού είναι μεγαλύτερη, ενώ με κόκκινο αποδίδονται τα σημεία του υδραγωγείου τα οποία βρίσκονται σε περιοχές με μικρή κλίση.

3. Χάρτης με τα αποτελέσματα της Cost Distance ανάλυσης. Η ανάλυση αυτή υπολογίζει τη σωρευτικά μικρότερη απόσταση κόστους για κάθε κελί της περιοχής μελέτης σε συνάρτηση με την επιφάνεια κόστους, η οποία έχει ορισθεί σύμφωνα με τις κλίσεις του αναγλύφου της περιοχής. Στην εικόνα 12 απεικονίζονται τα σημεία του υδραγωγείου που βρίσκονται σε περιοχές με χαμηλές τιμές, σύμφωνα με την ανάλυση (Εικ. 12).



Εικόνα 12 Αποτελέσματα της Cost Distance ανάλυσης. Με σκούρο μπλε αποδίδονται σημεία του ανάγλυφου που έχουν το μεγαλύτερο «κόστος ροής», σύμφωνα με τις κλίσεις των γειτονικών τους σημείων. Με κόκκινο αποδίδονται τα σημεία του υδραγωγείου τα οποία βρίσκονται σε περιοχές με μικρό «κόστος ροής».

4. Χάρτης με τα αποτελέσματα της Cost Back Link ανάλυσης. Η ανάλυση αυτή βαθμονομεί τα κελιά της επιφάνειας με το «κόστος ροής», σύμφωνα με τα γειτονικά του σημεία, με στόχο να βρεθούν τα κελιά με τη λιγότερο σωρευτική πορεία κόστους (Εικ. 13).



Εικόνα 13 Αποτελέσματα της Cost Back Link ανάλυσης. Οι περιοχές με τα θερμό χρώμα αποτελούν περιοχές με μεγαλύτερο κόστος ροής.

Σημαντικό στοιχείο για την ακρίβεια των αποτελεσμάτων της ανάλυσής της αποτελεί η κλίση της διαδρομής, η οποία εκτιμάται στο 0,96% (Koldewey 1890, 67 και γενικά για τις κλίσεις των υδαταγωγών: Καϊάφα 2008, 68, σημ. 50, με αναφορές στο Βιτρούβιο (VIII, 6, 1) και στον Πλίνιο (N.H. XXXI, 57). Μια τέτοια κλίση έχει ως αποτέλεσμα την κάθοδο της διαδρομής του νερού καθ' ύψος 0,3 μ. για κάθε 30 μ. επικλινούς πορείας του στο ανάγλυφο.

Για τη χωρική ανάλυση και τη μοντελοποίηση της διαδρομής του υδραγωγείου της Μυτιλήνης λάβαμε υπόψη τα χαρακτηριστικά των ρωμαϊκών υδραγωγείων (Hodge 1992, 172–184):

- Η ροή των υδραγωγείων είναι πάντοτε προς μία κατεύθυνση
- Ακολουθούν επικλινείς κατηφορικές διαδρομές
- η πορεία τους είναι ελεγχόμενη και η κλίση τους είναι σταθερή (Καϊάφα 2008, 324).

Συμπεράσματα-Αποτελέσματα

Με τη βοήθεια των Γ.Σ.Π., διαπιστώθηκε ότι τα οικοδομικά κατάλοιπα του υδραγωγείου και κατ' επέκταση η πορεία του, είχαν τοποθετηθεί λαθεμένα στους παλαιότερους χάρτες και πλέον για πρώτη φορά έχουμε τα εναπομείναντα σημεία αυτού του μεγάλου τεχνικού έργου χαρτογραφημένα με μεγάλη ακρίβεια. Η συνέχεια της έρευνας πιστεύουμε ότι θα είναι αποκαλυπτική για τον εντοπισμό της συνολικής πορείας του υδραγωγείου. Οι υψομετρικές διαφορές από σημείο σε σημείο φανερώνουν τις κλίσεις και επίσης μας βοηθάνε να αποκλείσουμε κάποια άλλα τεχνικά έργα που βρίσκονται στην περιοχή διέλευσης (π.χ. γέφυρες, πήλινοι κυλινδρικοί αγωγοί), αλλά δεν αποτελούν δομικά στοιχεία του υδραγωγείου.

Η χρήση των Γεωγραφικών Συστημάτων Πληροφοριών είναι απαραίτητη, προκειμένου να αναλύσει τη διαδρομή των υδραγωγείων και τη σχέση της πορείας του με την τοπογραφία του τοπίου το οποίο και διασχίζει.

Στην περίπτωση του υδραγωγείου της Μυτιλήνης οι αναλύσεις αυτές αποδεικνύεται ότι πρέπει να χρησιμοποιούν τη χωρική ανάλυση ως μια διερευνητική διαδικασία και όχι ως επεξηγηματικό εργαλείο. Ως προς την παρούσα μελέτη οι μεγάλες σε κλίμακα ανθρωπογενείς επιπτώσεις στο ανάγλυφο της περιοχής (Εικ. 14), ο σχετικά μικρός αριθμός εναπομεινάντων τμημάτων του υδραγωγείου και τα λίγα χωρικά δεδομένα, έχουν ως συνέπεια τα αποτελέσματα της μελέτης να έχουν μεγάλα περιθώρια σφάλματος.

Για τη διόρθωση των σφαλμάτων απαιτείται πολύ μεγαλύτερη ακρίβεια στην αρχαιολογική πληροφορία, η οποία μπορεί να αποκτηθεί με τοπογραφική αποτύπωση όλων των καταλοίπων. Ταυτόχρονα η εύρεση και γεωαναφορά χαρτών παλαιότερων περιόδων, αλλά και θέσεων (landmarks) που σχετίζονται με το υδραγωγείο θα βοηθήσει ώστε να αναπαρασταθεί το δυνατόν ρεαλιστικότερα το ανάγλυφο της περιόδου κατασκευής και λειτουργίας του.

Εικόνα 14 Λαξευμένος και κτιστός αγωγός στη θέση Λαρισαίες Πέτρες. Παράδειγμα ανθρωπογενούς καταστροφής.

Είναι επιβεβλημένος ο συνδυασμός των αναλυτικών δυνατοτήτων των Γ.Σ.Π. και της επιτόπιας αρχαιολογικής έρευνας και αποτύπωσης ώστε να μπορούν να παραχθούν ασφαλή συμπεράσματα για τη συνολική διαδρομή του, το πραγματικό μήκος και την υψομετρική διαφορά από τις πηγές υδροληψίας έως την τελική δεξαμενή συγκέντρωσης και διανομής του νερού (castellum). Ο Koldewey στα τέλη του 19ου αι. αναφέρει ως μήκος του υδραγωγείου τα 26 χλμ. και ως υψομετρική διαφορά από τις πηγές του Ολύμπου στην πόλη τα 250 μ. (Koldewey 1890, 65–68), μετρήσεις όμως που δεν έχουν επιβεβαιωθεί έως σήμερα.

Πρόσθετα στοιχεία για τον εντοπισμό κατάλοιπων του υδραγωγείου μπορούν να δώσουν μετά από επεξεργασία γεωφυσικές διασκοπίσεις, δορυφορικές απεικονίσεις, καθώς και αεροφωτογραφίες αρχείου.
Η συνέχιση της παρούσας έρευνας δημιουργεί τις προοπτικές σχεδιασμού ενός ερευνητικού προγράμματος με συμμετοχή της αρμόδιας Εφορείας Αρχαιοτήτων, του Πανεπιστημίου Αιγαίου και της Τοπικής Αυτοδιοίκησης για την επιβεβαίωση της πλήρους διαδρομής, της υψομετρικής διαφοράς, αλλά και της κλίσης των αγωγών του ρωμαϊκού υδραγωγείου Μυτιλήνης. Επιπρόσθετα, η εύρεση του συνόλου της πορείας του υδραγωγείου θα μπορούσε να βοηθήσει στην ανάδειξη των μοναδικών αρχαιοτήτων της περιοχής διέλευσής του και να αποτελέσει μια υψηλής ποιότητας πολιτιστική περιπατητική διαδρομή μέσα στο λεσβιακό τοπίο.

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ΑΝΑΖΗΤΗΣΗ ΟΔΙΚΩΝ ΔΙΚΤΥΩΝ ΕΠΙΚΟΙΝΩΝΙΑΣ ΚΑΤΑ ΤΗ ΝΕΟΛΙΘΙΚΗ ΠΕΡΙΟΔΟ ΣΤΗ ΝΑ ΘΕΣΣΑΛΙΑ ΜΕΣΩ ΧΩΡΙΚΗΣ ΑΝΑΛΥΣΗΣ ΜΕ GIS

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***Περίληψη/* Abstract**

Η χρήση τεχνικών χωρικής ανάλυσης των Συστημάτων Γεωγραφικών Πληροφοριών αποτελεί μια ήδη παγιωμένη τακτική σε προσεγγίσεις που αποσκοπούν στην αποκωδικοποίηση οικιστικών συμπεριφορών των κοινωνιών του παρελθόντος. Στο άρθρο επιχειρείται να προταθούν αφενός συγκεκριμένοι δίοδοι επικοινωνίας μεταξύ των οικισμών και αφετέρου να συζητηθεί η χρησιμότητα μιας τέτοια προσέγγισης και οι προοπτικές που ανοίγονται στην έρευνα. Για το σκοπό αυτό χρησιμοποιούνται τεχνικές χάραξης διαδρομών ελάχιστου κόστους μεταξύ συγκεκριμένων οικισμών της Νεολιθικής περιόδου στη ΝΑ Θεσσαλία, επί του ψηφιακού μοντέλου εδάφους. Διατυπώνεται η υπόθεση, ότι οι προτεινόμενες διαδρομές πιθανόν να λειτουργούσαν διαχρονικά ως ελκυστές για τη δημιουργία μεταγενέστερων οικισμών σε συγκεκριμένες θέσεις κατά μήκος της πορείας τους. Επιπλέον, σε επίπεδο έρευνας, μπορούν να χρησιμεύσουν ως ένα νέο εργαλείο ομαδοποίησης των οικισμών προκειμένου να μελετηθούν ενδεχόμενα δίκτυα ανταλλαγών, επαφών αλλά και πρωταρχικών ιεραρχικών δομών οργάνωσης, όσον αφορά την εξάπλωσή των νεολιθικών κοινοτήτων στο χώρο.

It is attempted to explore the habitation patterns of prehistoric Neolithic societies in eastern Thessaly, Greece, using GIS techniques of Spatial Analysis. Particularly, hypothetical routes of communication are proposed, based on the terrain accessibility as it is calculated through the use of a Digital Elevation Model. It is finally assumed that the proposed routes may have operated over time as attractors for the creation of subsequent settlements in specific places along their course. Moreover, the routes can serve as a new tool for grouping the settlements into possible exchange networks and primary hierarchical structures, regarding the spread of Neolithic communities in the area.

Λέξεις Κλειδιά: Νεολιθική; Θεσσαλία; GIS; Spatial Analysis; Least Cost Path; Visibility

Εισαγωγή

Από τις αρχές του 20ου αιώνα, όταν διαπιστώθηκε ότι στη Θεσσαλία διασώζεται ένας μεγάλος αριθμός διάσπαρτων νεολιθικών οικισμών, κυρίως με τη χαρακτηριστική μορφή των χαμηλών γηλόφων, τέθηκε το θέμα της ερμηνείας της κατανομής τους στο χώρο (Τσούντας 1908, Wace & Thompson 1912).

Παράλληλα με την έρευνα που αφορούσε στην μορφή και την εσωτερική οργάνωση του κάθε νεολιθικού οικισμού, άρχισαν να δημιουργούνται κατάλογοι με απεικόνιση της διασποράς τους πάνω σε χάρτες. Προτάθηκε σχεδόν αμέσως η ύπαρξη ισχυρής θετικής συσχέτισης της θέσης των οικισμών με παρακείμενες πηγές νερού, ρέματα ή ποτάμια (Τσούντας 1908). Παρατηρήθηκε επίσης αυξομείωση των οικισμών ανάμεσα σε υποπεριόδους της Νεολιθικής Εποχής. Αργότερα, νεότεροι ερευνητές παρατήρησαν ότι κατά τις πρώτες εκείνες προσπάθειες μελέτης της κατανομής των νεολιθικών οικισμών υπήρχε ισχυρή συσχέτιση των οικισμών που απεικονίζονταν στους χάρτες με τα σύγχρονα συγκοινωνιακά δίκτυα (σιδηροδρομική γραμμή, οδικοί άξονες), τα οποία χρησιμοποιούσαν οι παλαιότεροι ερευνητές για τις μετακινήσεις τους και τις έρευνές τους (Gallis 1979).

1. Το πλαίσιο της έρευνας

Τη δεκαετία του 1970 ξεκίνησε μια μεγάλη εκτεταμένη επιφανειακή έρευνα από τον D. French και την Αγγλική Αρχαιολογική Σχολή Αθηνών με σκοπό, εκτός των άλλων, και την καταγραφή του συνόλου των προϊστορικών οικισμών στη Θεσσαλία (Θεοχάρης 1973, Halstead 1984, preface). Η σήμανσή τους έγινε με τοποθέτηση απλών κουκίδων σε ένα λευκό χάρτη που είχε μόνο το περίγραμμα της Θεσσαλίας. Η εργασία αυτή αποτέλεσε τη βάση για έναν πλήρη κατάλογο από τον P.Halstead στα μέσα της δεκαετίας του 1980, χωρίς όμως ιδιαίτερες χαρτογραφικές πληροφορίες (Halstead 1984, 232–244). Την ίδια περίοδο, με αφορμή τον αναδασμό των αγροτεμαχίων στην Κεντρική Θεσσαλική Πεδιάδα, καταγράφηκαν οι προϊστορικοί οικισμοί της περιοχής για πρώτη φορά με γεωγραφικές συντεταγμένες, στοιχεία έκτασης αλλά και πληροφορίες απόλυτου και σχετικού υψομέτρου για κάθε μία από αυτές (Γαλλής 1992). Αν και οι συντεταγμένες που δόθηκαν αποτελούν πολύτιμη και μοναδική για την εποχή πληροφορία, ωστόσο υπάρχουν μικρά σφάλματα καθώς υπολογίζονταν έμμεσα μετά από οπτικό έλεγχο της περιοχής και εντοπισμό του σημείου ενδιαφέροντος σε χάρτη με κλίμακα 1:50.000. Με βάση αυτή την εργασία εμφανίστηκαν και οι πρώτες προσεγγίσεις με τη χρήση συστημάτων GIS, σε μια προσπάθεια να προσδιοριστούν μεγέθη όπως η μέση απόσταση μεταξύ των οικισμών ανά περίοδο, η θέση τους σε σχέση με το υψόμετρο, βασικές μετρήσεις πυκνότητας κυρίως με πολύγωνα Thiessen, περιορισμένης έκτασης χρήση των μετρήσεων ορατότητας και τέλος μια πρώτη προσπάθεια εξέτασης περιβαλλοντικών παραγόντων σε σχέση με την πυκνότητα ή ακόμα και την ύπαρξη ή απουσία οικισμών σε συγκεκριμένες περιοχές (Demoule & Perlès 1993, Perlès 2001).

Παρόμοιες προσεγγίσεις με μια νέα εντατική επιφανειακή έρευνα και τη χρήση συστημάτων GPS και GIS, πραγματοποιήθηκαν πρόσφατα στην περιοχή της Μαγνησίας και ειδικότερα στην πεδιάδα του Αλμυρού, με σκοπό τη διερεύνηση της σχέσης του δομημένου οικιστικού χώρου με τον υπόλοιπο χώρο, όπου αναπτύσσονταν οι καθημερινές δραστηριότητες των νεολιθικών παραγωγών (Βουζαξάκης 2008α, 2008β, 2008γ & 2009). Η έρευνα αυτή βασίστηκε κυρίως σε μια μεγάλη συζήτηση που είχε ξεκινήσει ήδη από τη δεκαετία του 1980 και αφορά την κατανομή των ευρημάτων εκτός των οικιστικών περιοχών (off-site distribution) σε μια προσπάθεια ολιστικής οπτικής και μελέτης του χώρου (Bintliff & Snodgrass 1988).

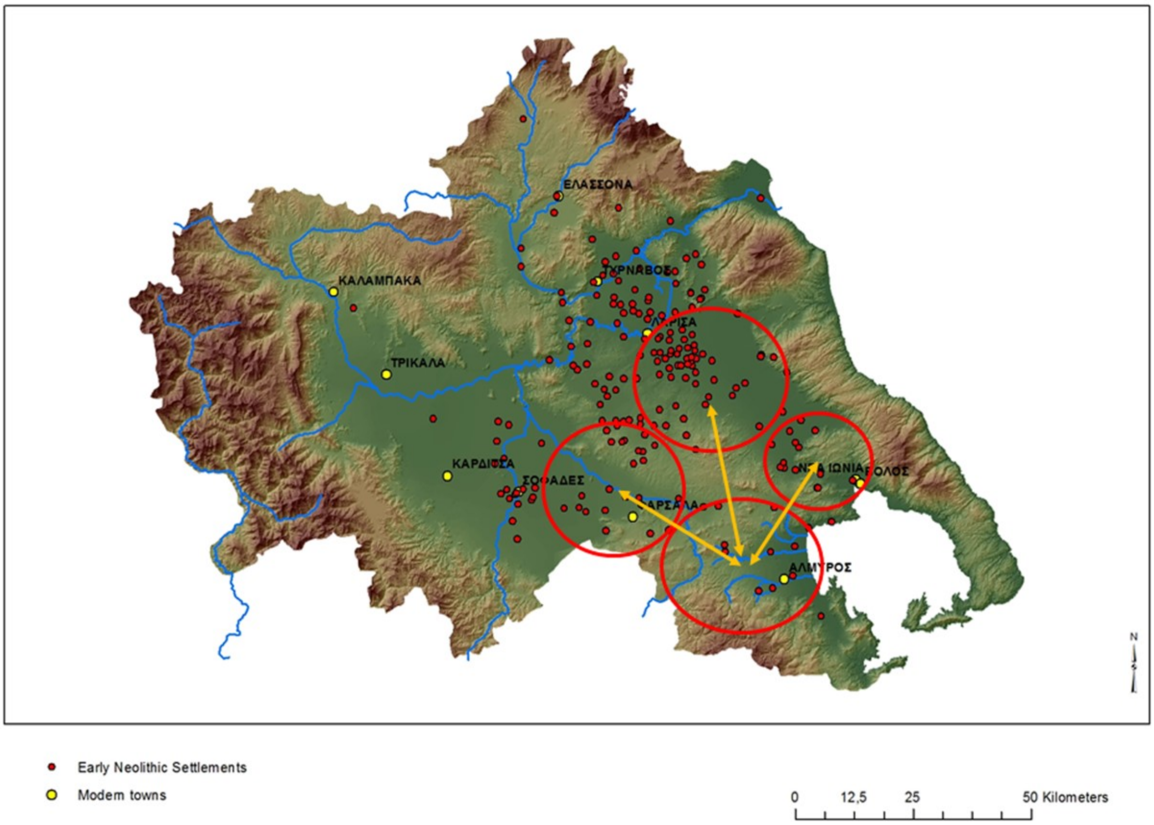
Με αφορμή παρόμοια ερωτήματα επιχειρήθηκε την τελευταία δεκαετία, επίσης, μια σειρά νέων ερευνών μέσα από διάφορα προγράμματα του Εργαστηρίου Γεωφυσικής - Δορυφορικής Τηλεπισκόπησης και Αρχαιοπεριβάλλοντος ΙΜΣ (Alexakis *et al.* 2008). Στο πρόγραμμα "Νεολιθική Θεσσαλία" καταγράφηκε το σύνολο των νεολιθικών οικισμών στη Θεσσαλία, αποτυπώνοντας τη γεωγραφική τους θέση επακριβώς με συντεταγμένες πάνω σε ψηφιακούς χάρτες με τη χρήση σύγχρονων ψηφιακών συστημάτων (GPS, δορυφορική τηλεπισκόπηση, GIS). Με βάση τα γεωλογικά δεδομένα από τη βιβλιογραφία (Demitrack 1986, 1994, Floras & Sgouras 2004) και από δεκάδες γεωτρήσεις που προϋπήρχαν και είχαν καταγραφεί σε όλη τη Θεσσαλία, υπολογίστηκαν τρεις διαφορετικές αναπαραστάσεις του φυσικού αναγλύφου (DEM με ανάλυση 1:50.000) για το χώρο της Θεσσαλίας, οι οποίες αντιστοιχούν στις τρεις διαφορετικές χρονικές περιόδους της Νεολιθικής Εποχής (Αλεξάκης 2008). Το αρχικό αυτό πρόγραμμα συνεχίζεται πλέον σήμερα με μια νέα μορφή που περιλαμβάνει επιπλέον εκτεταμένες σύνθετες γεωφυσικές έρευνες πάνω και γύρω από συγκεκριμένους νεολιθικούς οικισμούς, καθώς και επιπλέον επεξεργασία των δεδομένων μέσω δορυφορικής τηλεπισκόπησης, χημικών αναλύσεων εδάφους και του εμπλουτισμού της αρχικής βάσης δεδομένων με επιπλέον στοιχεία. Πρόκειται για το πρόγραμμα "IGEAN – Καινοτόμες γεωφυσικές προσεγγίσεις για την μελέτη των πρώιμων αγροτικών εγκαταστάσεων της Νεολιθικής Θεσσαλίας".

Με εφόδιο αυτά τα ψηφιακά ανάγλυφα εδάφους αλλά και την προϋπάρχουσα έρευνα και βιβλιογραφία, προτείνονται παρακάτω μια σειρά προσεγγίσεων σχετικά με τη θέση των οικισμών στο χώρο και τον τρόπο επικοινωνίας τους. Καταρχήν εξετάστηκε η δυνατότητα αξιοποίησης των δεδομένων και της τεχνολογίας για τον έλεγχο της ορατότητας γύρω από τους οικισμούς, καθώς και η δυνατότητα να διερευνηθούν πιθανές πεζοπορικές διαδρομές σύνδεσης των οικισμών μεταξύ τους, λαμβάνοντας υπόψη κυρίως το φυσικό ανάγλυφο της κάθε περιοχής. Πολύ απλά δηλαδή, επιχειρήθηκε η μετατόπιση από τις ευθείες γραμμές σύνδεσης των οικισμών που πρότειναν οι έρευνες των περασμένων δεκαετιών σε μια πιο ‘ρεαλιστική’ πρόταση διασύνδεσής τους, μέσα από πεζοπορικές διαδρομές που λαμβάνουν υπόψη τους το τρισδιάστατο ανάγλυφο της γήινης επιφάνειας.

Θα πρέπει ωστόσο εξαρχής να δηλωθεί ότι από την καθαρά αρχαιολογική οπτική, τα υπολογιστικά προγράμματα και οι τεχνικές που χρησιμοποιήθηκαν και που θα περιγραφούν παρακάτω, δεν χρησιμοποιήθηκαν σαν ένας θετικιστικός μηχανισμός παραγωγής απόλυτων ή οριστικών αληθειών και γνώσεων, αλλά ως αφορμή για περεταίρω συζήτηση, σε μια διαρκή ερμηνευτική προσέγγιση της ζωής και του κόσμου των νεολιθικών κοινωνιών της Θεσσαλίας.

2. Ο σχεδιασμός και η πρόταση ελέγχου υποθετικών πεζοπορικών διαδρομών μεταξύ των οικισμών

Η αρχική ιδέα ήταν να βρεθεί ένας τρόπος να προσομοιωθούν κάποιες υποθετικές διαδρομές που θα μπορούσαν να χρησιμοποιηθούν προκειμένου να μετακινηθεί κάποιος από συγκεκριμένους οικισμούς προς κάποιους άλλους. Οι διαδρομές αυτές θα έπρεπε να πληρούν συγκεκριμένες προϋποθέσεις. Πρώτον θα έπρεπε να λαμβάνουν υπόψη τους το φυσικό ανάγλυφο (κλίσεις εδάφους, δυσκολία πρόσβασης κλπ) με δεδομένο ότι θα έπρεπε να είναι εύκολα προσπελάσιμες από πεζούς, εφόσον κατά τη νεολιθική περίοδο δεν είχαν αρχίσει ακόμα να χρησιμοποιούνται τα ζώα ως υποζύγια. Δεύτερον θα έπρεπε να είναι οι ευκολότερες και συντομότερες δυνατές συνυπολογίζοντας μαζί με την ευκολία προσπελασιμότητας και τον απαιτούμενο χρόνο για



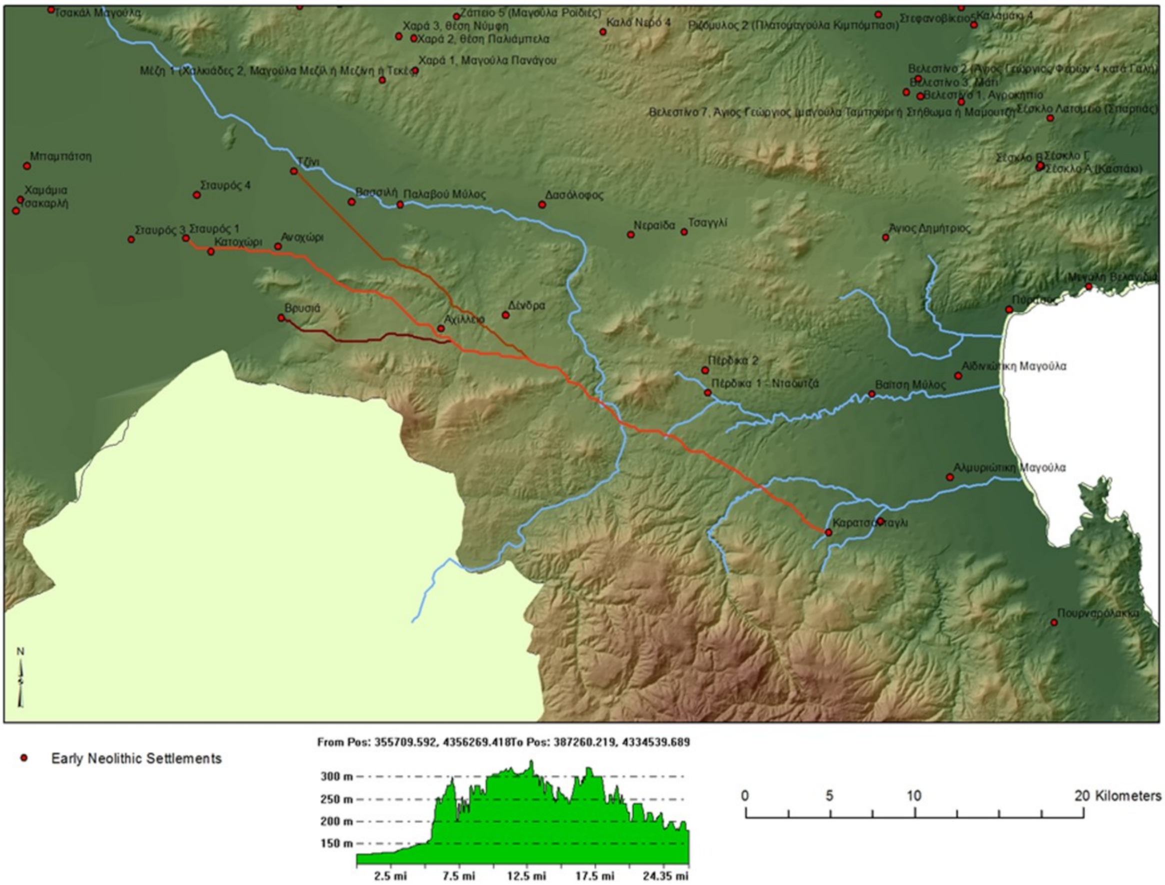
Εικόνα 1 Χάρτης της Θεσσαλίας με τους Νεολιθικούς οικισμούς και τις τέσσερις περιοχές ελέγχου.

την ολοκλήρωσή τους. Τρίτον εφόσον θα λειτουργούσαν ως δίοδοι αμφίπλευρης επικοινωνίας θα έπρεπε να πληρούν τα παραπάνω κριτήρια κατά την μετακίνηση και προς τις δύο κατευθύνσεις.

Ως εργαλείο για το σχεδιασμό τέτοιων υποθετικών διαδρομών επιλέχθηκε η δυνατότητα της εφαρμογής Arcgis 10.1 να υπολογίζει τη λεγόμενη 'διαδρομή ελάχιστου κόστους' (least cost path). Σημεία αφετηρίας και κατάληξης αποτέλεσαν διάφοροι οικισμοί όπως θα αναλυθεί παρακάτω. Ως επιφάνεια φυσικού αναγλύφου χρησιμοποιήθηκαν τα τρία DEM αρχεία που προαναφέρθηκαν, ενώ ως επιφάνεια τριβής χρησιμοποιήθηκε ένα αρχείο με τιμές υπολογισμένες για κάθε pixel με βάση την συνάρτηση για την πεζοπορία του Tobler, η οποία λαμβάνει υπόψη κυρίως την κλίση του εδάφους και τον προσανατολισμό του (Tobler 1993). Προφανώς στον πραγματικό κόσμο της νεολιθικής περιόδου θα επηρέαζαν και άλλοι παράγοντες την επιλεγμένη διαδρομή, καθώς και την ταχύτητα ή την ευκολία προσπέλασης ενός τόπου από έναν πεζοπόρο. Τέτοιοι παράγοντες ίσως ήταν η ύπαρξη ελών ή δασών, κάποια τεχνικά έργα μικρότερης ή μεγαλύτερης κλίμακας, αλλά και κοινωνικοί και ιδεολογικοί παράγοντες, όπως απαγορευμένες περιοχές ή αντίθετα περιοχές που λειτουργούσαν ως τοπόσημα και ως εκ τούτου πιθανόν ελκυστικά (π.χ. μια πηγή νερού). Δυστυχώς όμως η αρχαιολογική έρευνα δεν έχει κατορθώσει ακόμα να αναγνωρίσει τέτοιες περιοχές προκειμένου να ληφθούν υπόψη.

2α. Οι πρώτες απόπειρες διερεύνησης διαδρομών εντός της πεδιάδας Αλμυρού.

Αρχικά, ελέγχθηκαν κάποιες διαδρομές εντός της Πεδιάδας του Αλμυρού, με αφετηρία και κατάληξη οικισμούς της Αρχαιότερης Νεολιθικής Περιόδου (ΑΝ) (Βουζαξάκης 2008α, 233 κ. εξ.). Η πεδιάδα του Αλμυρού επιλέχθηκε ως μια αρκετά καλά ερευνημένη περιοχή για την περίοδο της Νεολιθικής (Μαλακασιώτη 1997, Μαλακασιώτη *et al.* 2008, Καλογιάννη *et al.* 2007, Reinders 2004, Ροντήρη 2004, 2005, Βουζαξάκης 2006, 2007, υπό έκδοση α, β, 2008, 2009, 2011). Η περίοδος της ΑΝ επιλέχθηκε κυρίως επειδή σε αυτή εμφανίστηκαν οι πρώτοι και παλαιότεροι νεολιθικοί οικισμοί και μπορούμε κατά συνέπεια να υποθέσουμε ότι τότε διαμορφώθηκαν και εγγράφηκαν στο χώρο τα πρώτα οδικά δίκτυα επικοινωνίας. Ενδιαφέρον παρουσιάζουν οι υποθετικές διαδρομές που ενώνουν τους πλέον απομακρυσμένους οικισμούς της περιοχής καθώς διασχίζουν μεγαλύτερες αποστάσεις διατρέχοντας από άκρο σε άκρο ολόκληρη την πεδιάδα. Η πρώτη απλή οπτική παρατήρηση που προέκυψε ήταν ότι κάποιες διαδρομές διέρχονταν πολύ κοντά από ενδιάμεσους οικισμούς της ίδιας περιόδου, χωρίς



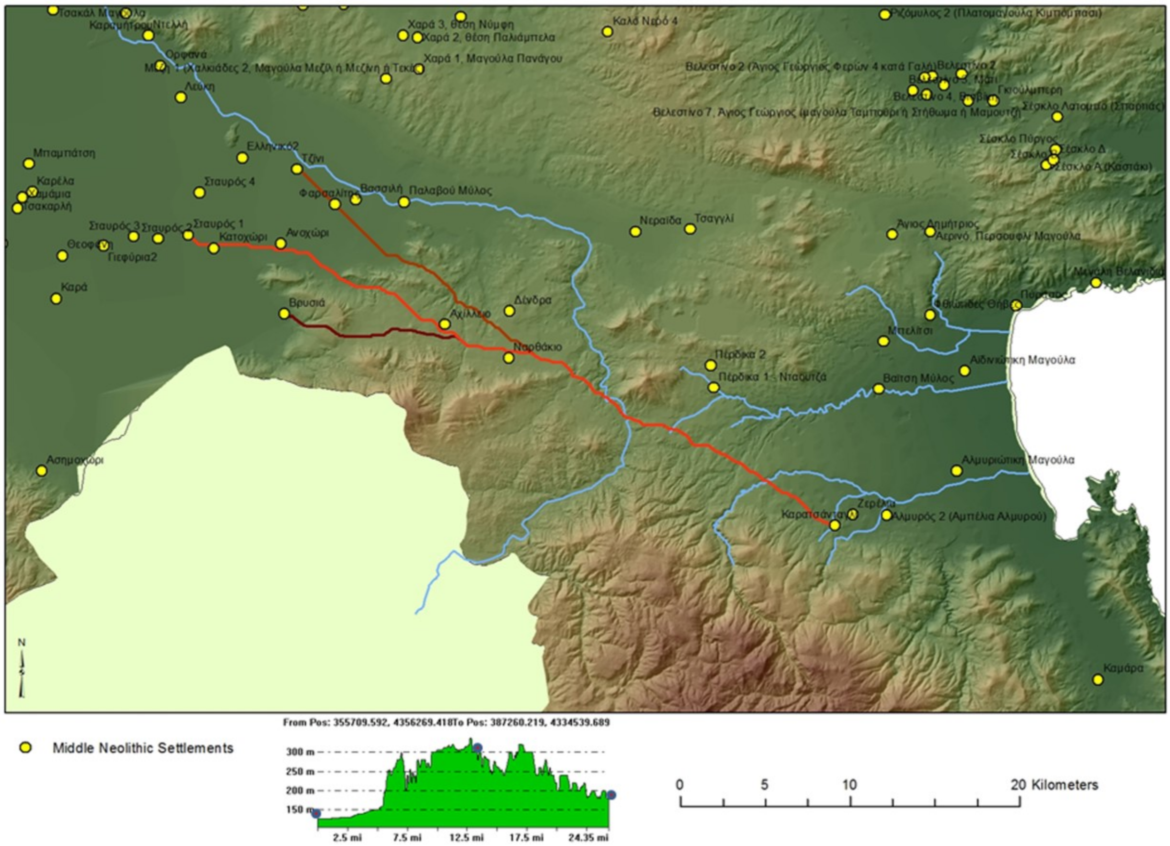
Εικόνα 2 Ομάδα διαδρομών από νότια της πεδιάδας Αλμυρού προς πεδιάδα Φαρσάλων. Εικονίζονται οι οικισμοί της Αρχαιότερης Νεολιθικής.

αυτοί να έχουν ληφθεί υπόψη κατά τη δημιουργία της εκάστοτε διαδρομής. Αυτή η παρατήρηση φαίνεται να ενισχύεται μόλις προβληθούν οι οικισμοί της Μέσης Νεολιθικής Περιόδου (ΜΝ) και της Νεότερης (ΝΝ). Υπάρχει συνεπώς η εντύπωση ότι οι μεταγενέστεροι οικισμοί αναπτύσσονταν με την πάροδο του χρόνου σχετικά κοντά με τις προϋπάρχουσες διαδρομές. Ωστόσο, σε μια περιοχή που είναι λίγο πολύ επίπεδη, με μικρές υψομετρικές διαφορές και κλίσεις θεωρήθηκε ότι η εικόνα μπορεί και να ήταν πλασματική.

2β. Επέκταση του εγχειρήματος διερεύνησης διαδρομών μεταξύ των γειτονικών πεδιάδων Αλμυρού, Φαρσάλων και Βελεστίνου

Αποφασίστηκε λοιπόν να δοκιμαστεί το μοντέλο με διαδρομές που να ενώνουν οικισμούς από γειτονικές περιοχές, οι οποίες χωρίζονται με λοφώδεις ή και ορεινές εκτάσεις (Βουζαξάκης 2011). Με τον τρόπο αυτό οι προτεινόμενες διαδρομές ελάχιστου κόστους θα "αναγκάζονταν" να λάβουν υπόψη τους ένα πιο πολύπλοκο φυσικό ανάγλυφο με αξιοσημείωτες υψομετρικές διαφορές και κλίσεις εδαφών. Επιλέχθηκαν τέσσερις περιοχές (Εικ. 1): Η πεδιάδα του Αλμυρού, η πεδιάδα γύρω από τα Φάρσαλα που αποτελεί και την είσοδο από νοτιοδυτικά για ολόκληρη την πεδιάδα της Καρδίτσας, η πεδιάδα του Βελεστίνου που ενώνεται και αυτή στην ουσία με την πεδιάδα της Λάρισας και η περιοχή – πεδιάδα του Βόλου. Όλες αυτές οι περιοχές χωρίζονται μεταξύ τους από χαμηλότερους ή ψηλότερους λόφους και έντονα πτυχωμένα ανάγλυφα σε αντίθεση πάντα με το επίπεδο ανάγλυφο που παρουσιάζουν οι ίδιες.

Ενδεικτικά η πρώτη ομάδα διαδρομών που θα μας απασχολήσει και που παρουσιάζει ενδιαφέρον είναι οι διαδρομές με αφετηρία το ΝΔ άκρο της πεδιάδας του Αλμυρού και καταλήγουν στην περιοχή των Φαρσάλων διερχόμενες από τη λοφώδη έκταση στο ενδιάμεσο (Εικ. 2, 3). Επιλέχτηκε ως αφετηρία ο οικισμός Καρατσάνταγλι και ως τερματισμός οι οικισμοί Βρυσιά, Τζίνι και Σταυρός 1. Στο σημείο αυτό θα πρέπει να σημειωθεί ότι η σχεδίαση μεγάλων σε απόσταση διαδρομών στο πειραματικό αυτό μοντέλο εξυπηρετεί στη διερεύνηση των περασμάτων από τη μια πεδιάδα στην άλλη μέσω των ενδιάμεσων λόφων, χωρίς να σημαίνει κατ' ανάγκη ότι κάποιος θα διένυε απευθείας τα 45 ή 50 χιλιόμετρα της απόστασής τους. Σε αυτό όμως το θέμα θα επανέλθουμε αργότερα.

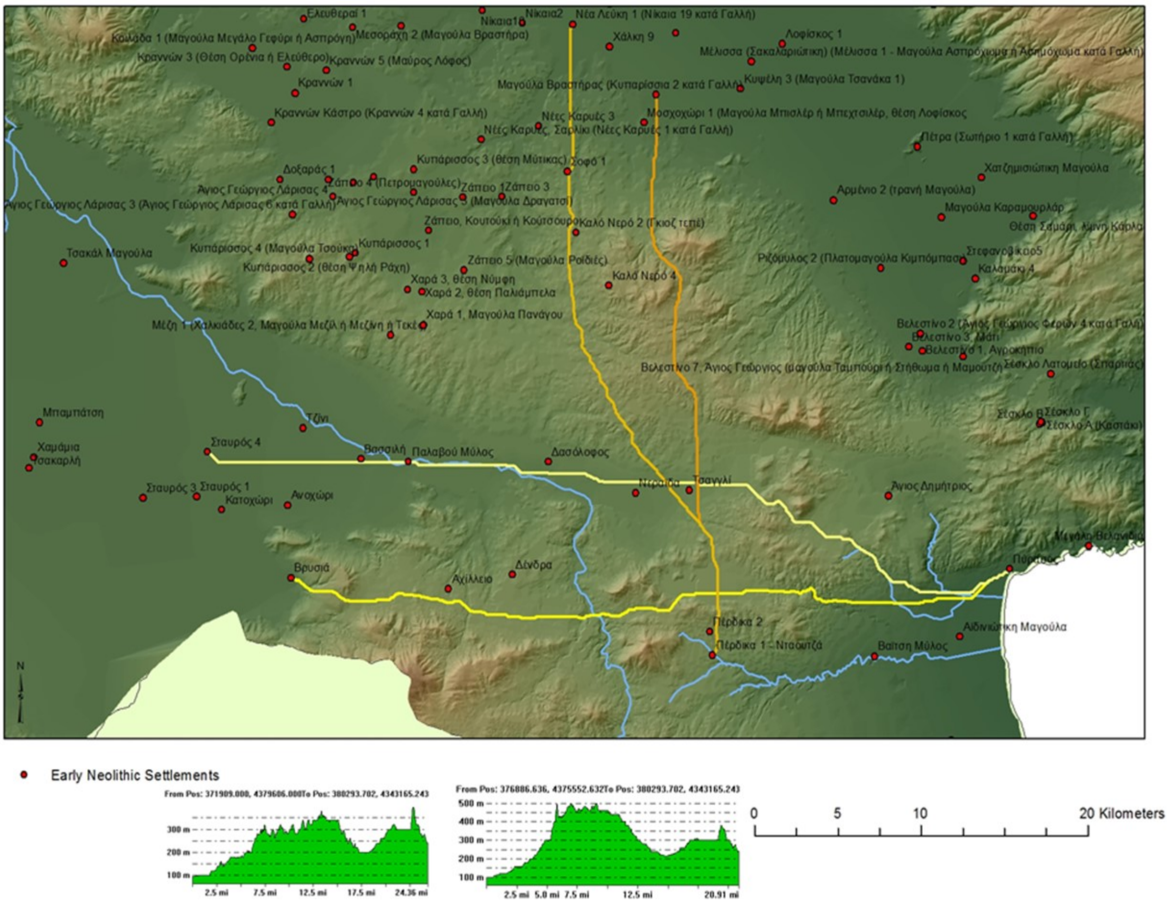


Εικόνα 3 Ομάδα διαδρομών από νότια της πεδιάδας Αλμυρού προς πεδιάδα Φαρσάλων. Εικονίζονται οι οικισμοί της Μέσης Νεολιθικής.

Παρατηρήθηκε λοιπόν ότι ως ένα σημείο οι τρεις διαδρομές ταυτίζονται για να διαχωριστούν η κάθε μία σε διαφορετικό σημείο, πάνω στους λόφους. Ήδη από την αρχαιότερη Νεολιθική περίοδο διαπιστώνεται ότι οι οικισμοί που είναι γνωστοί στην περιοχή εμπίπτουν σε μια ακτίνα 250-500 μ. εκατέρωθεν των συγκεκριμένων διαδρομών. Ειδικά ο οικισμός του Αχιλλείου (Gimbutas *et al.* 1989), όχι μόνο βρίσκεται μέσα στη ζώνη των 500μ από τη διαδρομή προς τον Σταυρό 1, αλλά και κοντά (περίπου 900μ.) από το σημείο όπου διαχωρίζονται οι διαδρομές με κατεύθυνση προς Σταυρό 1 και Βρυσιά. Παρόμοια όταν προβληθούν οι οικισμοί της Μέσης νεολιθικής περιόδου ο οικισμός στη θέση Φαρσαλίτης βρίσκεται επάνω στη διαδρομή προς Τζίνι ενώ ο οικισμός στο Ναρθάκιο εμφανίζεται μέσα στη ζώνη των 500μ της διαδρομής προς Σταυρό 1 και περίπου 1400μ δυτικά από το σημείο που αυτή διαχωρίζεται από την διαδρομή προς Τζίνι.

Περνώντας στη δεύτερη ομάδα διαδρομών (εικ. 4) με αφετηρία την ανατολική πλευρά της πεδιάδας του Αλμυρού και ειδικότερα την Πύρασο, διαπιστώνουμε ότι στο ίδιο σημείο κοντά στο Ναρθάκιο φαίνεται να διασταυρώνεται και η διαδρομή προερχόμενη από την Πύρασο προς την Βρυσιά. Εντός της ζώνης των 250 μ. εκατέρωθεν από αυτή τη διαδρομή εντοπίζεται ο οικισμός της Μέσης Νεολιθικής στη θέση Μπελίτσι (Βουζαξάκης 2006, 2007). Με αφετηρία την Πύρασο υπολογίστηκαν και δύο ακόμα ενδιαφέρουσες διαδρομές προς τους οικισμούς Σταυρός 1 και 4, στην πορεία των οποίων και μάλιστα στη ζώνη των 250 μέτρων εκατέρωθέν τους βρίσκονται πέντε οικισμοί της Αρχαιότερης Νεολιθικής, έξι της Μέσης Νεολιθικής και επτά της Νεότερης Νεολιθικής. Θα μπορούσαν, συνεπώς, το Ναρθάκιο και το Αχίλλειο να αποτελούν σταυροδρόμια και σημεία αναφοράς στο συγκεκριμένο δίκτυο επικοινωνίας; Προς αυτή την κατεύθυνση, του κομβικού ρόλου κάποιων οικισμών (με ειδική αναφορά στο Αχίλλειο) σε ένα δίκτυο επικοινωνίας και ανταλλαγών φαίνεται πως καταλήγει και σχετική μελέτη σε σχέση με την κεραμική (Πεντεδέκα 2008)

Σχεδιάζοντας ανάλογες διαδρομές στον άξονα Βορρά – Νότου, με αφετηρία τον οικισμό Πέρδικα 1, προέκυψαν δύο ενδιαφέρουσες διαδρομές με κατεύθυνση προς την κεντρική περιοχή της πεδιάδας της Λάρισας και συγκεκριμένα τους οικισμούς Νίκαια 19 και Κυπαρίσσια 2 αντίστοιχα. Η πρώτη καθώς διέρχεται τους λόφους βρίσκεται κοντά σε 4 οικισμούς της Αρχαιότερης και Μέσης Νεολιθικής, ενώ η πορεία της δεύτερης συμπίπτει με τη θέση ενός οικισμού της Νεότερης Νεολιθικής. Οι δύο



Εικόνα 4 Συνδυαστική απεικόνιση διαδρομών από την πεδιάδα Αλμυρού προς την πεδιάδα Φαρσάλων και την πεδιάδα Βελεστίνου.

διαδρομές φαίνονται να διαχωρίζονται μεταξύ τους και παράλληλα να διασταυρώνονται με την διαδρομή Πύρασος – Σταυρός 1 που ήδη αναφέραμε, στην ευρύτερη περιοχή των οικισμών Τσαγγλί (Wace & Thompson 1912) και Νεράιδα. Με βάση αυτή την εικόνα και κατ' αναλογία της παρατήρησης για το Αχίλλειο και το Ναρθάκιο, θα μπορούσε ο οικισμός στο Τσαγκλί να αποτελεί κόμβο και ενδιάμεσο σταθμό σε ένα ακόμα πιο εκτεταμένο δίκτυο κίνησης;

Συμπεράσματα

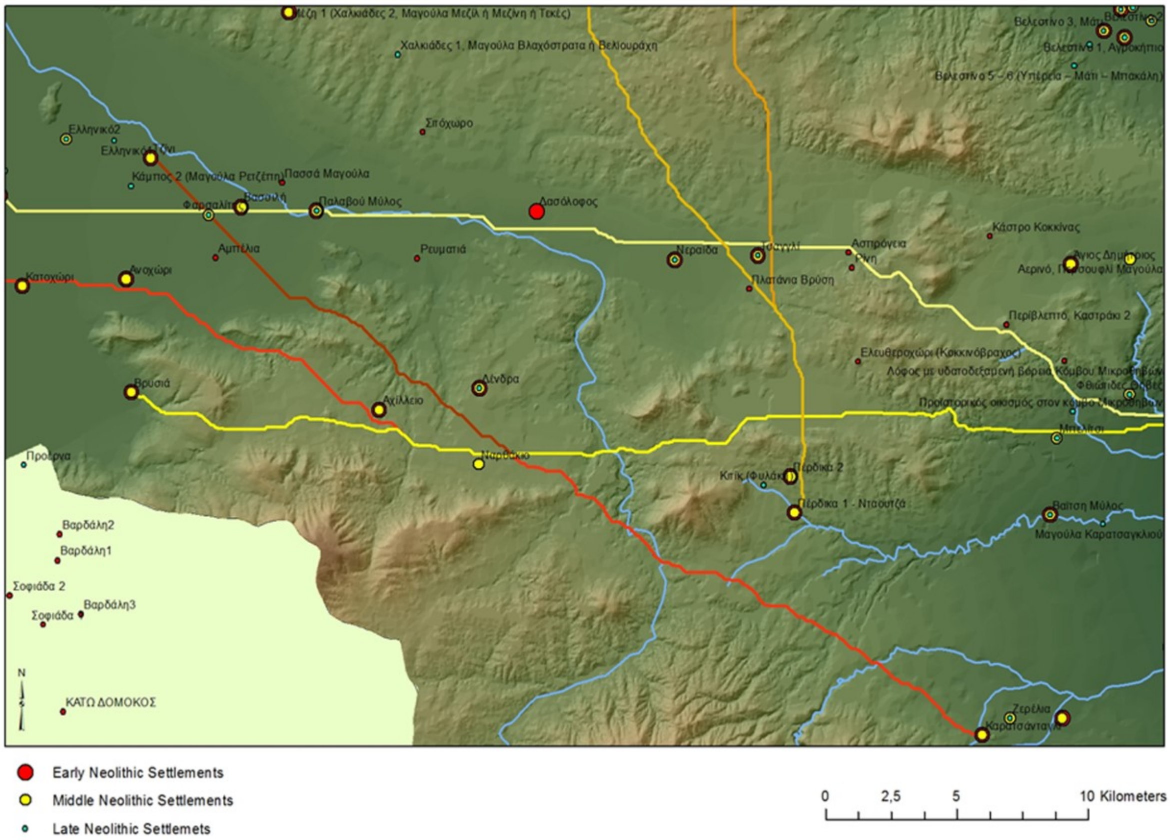
Με τον τρόπο αυτό ελέγχθηκαν πολλές πιθανές διαδρομές αρκετές από τις οποίες εμφάνιζαν παρόμοια χαρακτηριστικά ως προς τη σχέση τους με τη θέση των οικισμών. Τα χαρακτηριστικά αυτά θα μπορούσαν να συνοψισθούν ως εξής:

α) Ενώνοντας γεωγραφικά μακρινούς οικισμούς της Αρχαιότερης Νεολιθικής περιόδου και αναγκάζοντας το σύστημα να σχεδιάσει διαδρομές που διατρέχουν τις λοφώδεις περιοχές μεταξύ των διαφορετικών πεδιάδων, αρκετοί νεολιθικοί οικισμοί αυτής της περιόδου βρίσκονται μέσα στη ζώνη των 500μ. εκατέρωθεν των διαδρομών αυτών.

β) Διατηρώντας τις παραπάνω διαδρομές και προβάλλοντας στο χάρτη σταδιακά τους οικισμούς της Μέσης και της Νεότερης Νεολιθικής, προκύπτει σε αρκετές περιπτώσεις αυτοί να βρίσκονται επίσης μέσα στη ζώνη των 500 μ. εκατέρωθεν των διαδρομών.

γ) Κάποιοι οικισμοί της Αρχαιότερης Νεολιθικής εμφανίζονται κοντά σε σημεία όπου διασταυρώνονται ή διαχωρίζονται διαδρομές (Εικ. 4, 5). Σε παρόμοια σημεία υπάρχουν περιπτώσεις όπου εμφανίζονται οικισμοί σε μεταγενέστερες περιόδους εφόσον δεν υπήρχαν ήδη.

Με βάση τα παραπάνω μπορούν να διατυπωθούν μια σειρά σκέψεων προκειμένου το μοντέλο να ελεγχθεί περισσότερο και ενδεχομένως να αξιοποιηθεί ως ένα εργαλείο που μπορεί να παράγει νέες οπτικές στην έρευνα. Ενδεχομένως, οι θέσεις των πρώτων οικισμών να διαμόρφωσαν την αρχική μορφή δικτύων επικοινωνίας και μονοπατιών. Στο βαθμό όμως που αυτά διατηρήθηκαν και χρησιμοποιήθηκαν για χιλιετίες πιθανόν επηρέασαν μαζί και με άλλους παράγοντες την επιλογή της θέσης ίδρυσης νέων οικισμών διαμορφώνοντας έτσι την γενικότερη

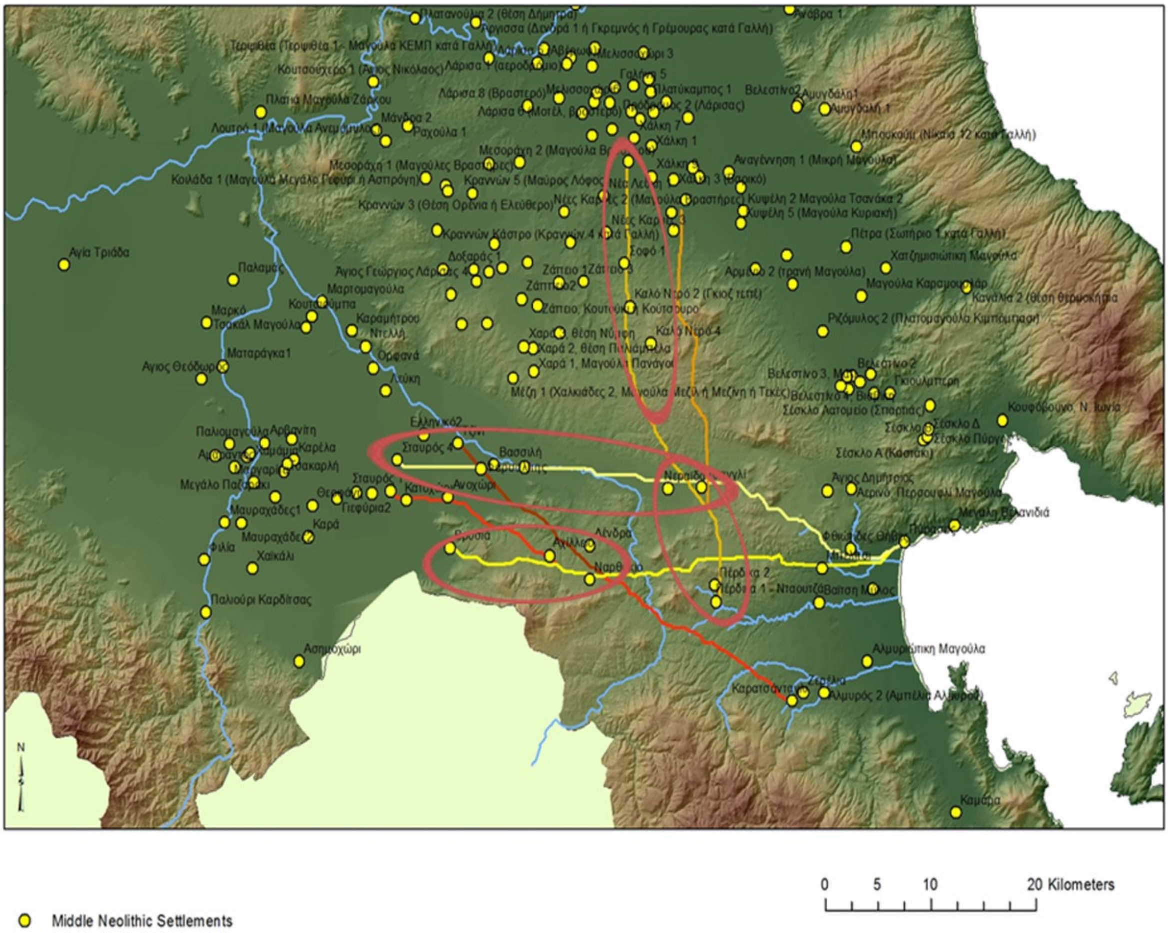


Εικ. 5 Σημεία διασταύρωσης διαδρομών.

εικόνα της διασποράς των οικισμών στις επόμενες περιόδους. Με βάση το σκεπτικό αυτό, οι οικισμοί αυτοί καθ' αυτοί πιθανόν να χρησίμευαν και ως ενδιάμεσοι σταθμοί και οδοδείκτες ενός εκτεταμένου δικτύου επικοινωνίας. Κατά συνέπεια η πολύ κοντινή απόσταση των οικισμών (Γαλλής 1992, Perlès 2001), εκτός όποιων άλλων οικονομικών και κοινωνικών αιτιών, ίσως αποτελούσε την προϋπόθεση και την στρατηγική λύση για τις μετακινήσεις μέσω κομβικών σημείων από το ένα μέρος στο άλλο με ασφάλεια, σιγουριά και χωρίς άσκοπες περιπλανήσεις στο χώρο, ειδικά αν αυτός υπήρξε δασωμένος και με περιορισμένη ως εκ τούτου ορατότητα παρόλο τον πεδινό του χαρακτήρα (Bottema 1994). Αν το παραπάνω ισχύει, δημιουργούνται μια σειρά νέων προβληματισμών και οπτικών, που μπορούν να εφαρμοστούν στο αρχαιολογικό υλικό. Με κατάλληλα διατυπωμένα ερωτήματα είναι δυνατόν να προκύψουν νέα δεδομένα για τα δίκτυα ανταλλαγών και επικοινωνίας μεταξύ των οικισμών σε τοπικό και ευρύτερο επίπεδο (Κωτσάκης 1996, Καρίμαλη 2000, 2001, Πεντεδέκα 2008). Αλλά ακόμα περισσότερο θα μπορούσαν να εξετασθούν υποθέσεις σε σχέση με τον τρόπο δημιουργίας και εγκατάστασης των οικισμών μέσω κοινωνικών διαδικασιών (διάσπαση, μετακίνηση, συνεργασία κλπ), που αφορούν συγκεκριμένους πλέον γειτονικούς οικισμούς, οι οποίοι βρίσκονται πάνω σε κοινά μονοπάτια και άξονες επικοινωνίας. Συνήθως οι μέθοδοι για τον έλεγχο της πυκνότητας των οικισμών και της ενδεχόμενης ομαδοποίησής τους στο χώρο επικεντρώνονται στην ανάλυση 'πλησιέστερου γείτονα' (nearest neighbour analysis) (Orton 1980, 145-146) – και στο σχεδιασμό πολυγώνων Thiesen επί του χάρτη (Orton 1980, 192). Οι ομαδοποιήσεις των οικισμών μπορούν πλέον να γίνουν όχι μόνο στη σχέση της ευθείας απόστασης και της αμεσότητας της γειτνίασής τους, αλλά και με βάση τη συνύπαρξή πάνω σε κοινούς άξονες επικοινωνίας (Εικ. 6). Το επόμενο βήμα είναι ο συνδυασμός του μοντέλου με τη σύγκριση αρχαιολογικών δεδομένων από τους ομαδοποιημένους πλέον οικισμούς. Προς την κατεύθυνση αυτή θα αποδειχθούν επίσης χρήσιμα τα αποτελέσματα των νέων τεχνικών Τηλεπισκόπησης και γεωφυσικών ερευνών που ήδη πραγματοποιούνται στην ευρύτερη περιοχή (βλ. υποσημ. 2).

Κλείνοντας, θα πρέπει να σημειωθεί ότι η προσέγγιση όπως διαμορφώθηκε παραπάνω, προφανώς είναι βαθύτατα επηρεασμένη από τις πολλές και επίπονες προσωπικές πεζοπορίες και επισκέψεις στους νεολιθικούς οικισμούς κατά τη διάρκεια της έρευνας, που ουσιαστικά δημιούργησαν την ιδέα για μια τέτοια οπτική, την οπτική του πεζοπόρου σε ένα τοπίο με φυσικά εμπόδια αλλά και επηρεασμένη από ένα θεωρητικό υπόβαθρο, που θεωρεί ότι η κίνηση ως διαδικασία και πράξη αποτελεί ουσιαστική δύναμη διαφοροποίησης και προσαρμογής του ανθρώπου, τόσο ως άτομο όσο και στο πλαίσιο μιας κοινωνικής ομάδας (Cresswell 2004, 43, Ingold 1993, 154). Είναι, ωστόσο, αδύνατο δυστυχώς με τις σημερινές γνώσεις για τη νεολιθική περίοδο και τους ανθρώπους της, σε αυτή την οπτική να συμπεριληφθεί πέρα από τη γεωγραφική και περιβαλλοντική διάσταση και μια περισσότερο κοινωνική και ιδεολογική, που προφανώς θα έκανε το όλο μοντέλο πιο ρεαλιστικό. Ενδεχομένως όμως, αν κατανοηθεί καλύτερα το προτεινόμενο μοντέλο και γίνουν αντιληπτές πέρα από τις κανονικότητές του και οι όποιες ασυμβατότητες που ενδεχομένως υπάρχουν, να σταθεί δυνατό να αναγνωριστούν και περιοχές αποφυγής ή προσέλκυσης με ιδιαίτερη κοινωνική ή ιδεολογική σημασία.

Είναι δεδομένο ότι η διερεύνηση των διαδρομών ελάχιστου κόστους με σημεία αφετηρίας και προορισμού τους νεολιθικούς οικισμούς της πεδιάδας του Αλμυρού και με επίπεδο αναφοράς την ψηφιακή προσομοίωση του φυσικού αναγλύφου, ξεκίνησε ως ένας θετικιστικός πειραματισμός στο πλαίσιο των δυνατοτήτων ενός υπολογιστικού προγράμματος διαχείρισης γεωγραφικών πληροφοριών, φάνηκε όμως ότι μπορεί να εξελιχθεί σε πολύτιμο εργαλείο αρχαιολογικής πλέον προσέγγισης ή έστω προβληματισμού και πειραματισμού.



Εικόνα 2 Ομαδοποίηση οικισμών με βάση τις προτεινόμενες διαδρομές.

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AN IMPROVED ALGORITHM FOR COST-SURFACE ALLOCATION ANALYSES: THE CASE-STUDY OF THE BRADANO VALLEY (BASILICATA, ITALY)

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Περίληψη/ Abstract

Τα Πολύγωνα Thiessen, επιτρέπουν τη δημιουργία ενός ιδανικού μοντέλου των περιοχών που ελέγχονταν από οικισμούς στην αρχαιότητα, αλλά λειτουργεί σε έναν απλό και αφηρημένο γεωγραφικό χώρο. Μια πιο εξελιγμένη προσέγγιση χρησιμοποιεί συσσωρευτικούς cost-surface χάρτες με σκοπό τη σύνδεση του εκάστοτε οικισμού με τον περιβάλλοντα φυσικό του χώρο. Αυτού του τύπου η ανάλυση λαμβάνει υπόψη τη μορφολογία του εδάφους καθώς και άλλα στοιχεία, όπως τα φυσικά εμπόδια, αλλά ξεκινά από την παραδοχή ότι ο κάθε οικισμός έχει την ίδια σπουδαιότητα. Σε αυτό το άρθρο παρουσιάζεται ένα νέο εργαλείο πληροφορικής για τη δημιουργία χαρτών κατανομής επιφάνειας κόστους: το εργαλείο αυτό εισάγει στον αλγόριθμο παραμέτρους που εξαρτώνται από τα βασικά χαρακτηριστικά του πληροφοριακού επιπέδου των αρχαιολογικών θέσεων, προκειμένου να παραχθούν πιο εξελιγμένα και ακριβέστερα μοντέλα. Το εργαλείο έχει δοκιμαστεί σε πειραματικό στάδιο στη μελέτη που σχετίζεται με την κατανομή των αρχαίων οικισμών της κοιλάδας του ποταμού Bradano (Basilicata, Ιταλία).

A Thiessen polygons model allows an ideal scheme of the territories controlled by archaeological settlements, but it works on a plain and abstract geographic space. A more sophisticated approach uses cumulative cost-surface maps to associate a portion of physical space to each settlement. This analysis can take into account the morphology of the territory and elements such as natural obstacles, but it starts from the assumption that each settlement has the same importance. In this paper, a new tool for creating cost-surface allocation maps is presented: in order to obtain more sophisticated and accurate models, this tool introduces the algorithm parameters that are dependent on attributes of the starting sites layer. The tool has been employed in the ancient settlements of the Bradano Valley (Basilicata, Italy).

Keywords: Bradano River valley, Landscape archaeology, Quantum GIS, Spatial analysis, accumulative cost-surface analysis, cost surface allocation, quantitative archaeology.

Introduction: Spatial analysis and Thiessen polygons in the archaeology of Southern Italy

In Italy, for more than twenty years, the infinite potential of GIS platforms has been widely acknowledged; today we recognize their increasing use in excavation projects and archaeological surveys. They are inserted, for example, (Forte 2002, D'Andrea 2006, Caravale 2009) into research projects to address the study of settlements patterns on large territorial portions. The spatial analysis capabilities, in particular, enable researchers to formulate hypotheses about spatial patterns as well as highlight the relationships between various sites in different periods of occupation. The potential of GIS tools for the study of settlement phenomena has been cited within the first review of archaeological projects conducted by the Italian journal *Archeologia e Calcolatori* which, since the late 90s, began to use GIS platforms (Moscati 1998, Scianna & Villa 2011). This work included the first archaeological projects that made systematic use of GIS software packages for the integrated management of satellite data and aerial photographs, as well as geographic, physiographic and archaeological elements. The ultimate goal was to perform queries and analysis of archaeological sites and, finally, at the interpretation level, to make spatial analyses. In most cases, the standard processing and the basic functions of GIS met the basic needs of researchers for the management of the immense amount of alphanumeric data and cartographic archives as well as the phasing of chronological periods and the study of artifacts and archaeological settlements. Despite the widespread use of these platforms, however, few projects go beyond the first levels of management and processing of data to deal with structuring capabilities that address issues of spatial analysis.

In Italy one of the main techniques for the study of regional settlement systems (also the most common in GIS platforms) is the application of the theoretical model of Thiessen polygons (Rendeli 1993, 99−106). During territorial research of the classical age in southern Italy, this method was used to simulate the area of influence and political control of each site; examples include the project in the territory of Brindisi in Puglia and the *Morgantina Survey* in Sicily (Cambi 2001, 376−378, Thompson 2000, 407−408). The project *Colline Metallifere* (Middle Age research), carried out in the valley of the river Bruna in Tuscany, the use of polygons allowed researchers to hypothesize the territories belonging to medieval castles and the close relationship between fortified sites and productive mining areas (Bianchi et al 1999, 163−166). These projects deal with relatively simple spatial analysis through the use of polygons. And it is useful to have an ideal scheme of the territories controlled by each settlement that is theoretically abstract. But we have also seen attempts to assume the extension of the areas belonging to the individual sites, which, overcoming the linear model and the two-dimensional Thiessen polygons, take into account the morphology of the landscape (including physical barriers). Examples include the use of GIS processing to study the settlement dynamics and the relationships between the various sites, as in the case of the territories of the ancient Daunia and Messapia (current name provinces of Foggia and Salento) (Pecere 2006, 206−207, Burgers 2009, 283) and, in Basilicata, at *Metaponto Survey* (Carter & Prieto 2011, 123−124).

1. Settlement dynamics of indigenous territories in lower Bradano and the Montescaglioso case study.

Here, we present a case study from the eastern Basilicata of southern Italy (Fig. 1), where we are applying a series of computer tools, based on GIS processing, to study the characteristics and the structure of the territorial settlement systems. This landscape archaeology project studies the territory transformations of the lower valley of the Bradano River, a corridor that has assumed strategic importance from the Archaic age; it is located in an intermediate area between the Peucetian territory, the Oenotrian (later Lucanian) hinterland and, where the river meets the sea on the Ionian coast, the Achaean *polis* of Metaponto which dates from the Greek colonial age. Working in the rural territory of Metaponto, the University of Texas research team has demonstrated that the structure of the ancient *chora* of the Greek colony extended from the coast to the Hinterland, which included many farmsteads and the so-called ‘dividing lines’ of the *chora* (Carter & Prieto 2011).

Figure 1 Map of the main ancient settlements of eastern Basilicata with the location of the Bradano River valley area.

However, one of the issues that remain is the organization of indigenous space settlements beyond the agrarian living space of Metaponto. In fact, besides the *chora* of the Greek *polis* and beyond the outer *eschatià*, along the lower valley of the Bradano, a number of important indigenous sites of archaeological interest are present; these include Monte Irsi, Grottole, Miglionico, Timmari and Montescaglioso (mostly dating from the Iron Age / 8th century BC – to the late Hellenistic period). All of these are hegemonic settlements located on elevated ground and form isolated upland systems that dominate the river valley; their position on the hilltops was functional, not least to exercise control over the surrounding territory. Under the coordination of the Postgraduate School of Archaeological Heritage of Matera (SSBA-UNIBAS), systematic intensive surveys to study the settlement dynamics of these indigenous territories are in place in the district of the Bradano valley and, more particularly, in the territory of Grottole - Altojanni (Osanna *et al.* 2007), of Timmari (Osanna *et al.* 2012), as well as in the territory of Montescaglioso (Roubis & Camia 2011, Roubis 2012).

The territory of Montescaglioso provides an excellent case study, because during the Archaic and the late Hellenistic period (7^{th}−1^{st} century BCE), it played a key role in the area between the indigenous world and the coastal plain inhabited by the Greeks of Metaponto. With our archaeological survey in Montescaglioso area, we have documented a series of new archaeological sites, related primarily to the agricultural use of the land. In this area, besides farms, archaeological research has identified two important villages: Difesa San Biagio and Pagliarone. The use of GIS platforms and the application of spatial analysis in the Montescaglioso case study, especially the cost surface allocation analysis, provide a useful simulation for Montescaglioso and the two villages named above. While they cannot provide definitive solutions, they may lead to new hypotheses.

[D.R.]

2. An improved algorithm for cost-based allocations

The problem of determining the boundaries of the territories owned or controlled by specific archaeological sites is well known, and we can divide all the solutions adopted by archaeologists into two main groups. Algorithms and formulas that were not directly developed by archaeologists, but are included in many GIS software packages and are relatively simple to adapt to archaeological contexts compose the first group. In the second group we can count all those functions and procedures that were specifically developed by archaeologists, in order to consider variables that are more related to archaeological phenomena. Thiessen polygons and cost surface allocation are the best examples of the first group of algorithms. Thiessen polygons, also known as Voronoi diagrams, are the easiest and the most common way of performing an allocation analysis (Angell & Moore 1984). The polygons are constructed simply by connecting the perpendiculars to the midpoints of the segments that unite each site to the nearest ones. A Thiessen polygon can be considered as the geometric place of the points that are closer to one of the starting sites than to any other (Fig. 2).

Thiessen polygons were first used in archaeology in the 1970's (Hodder & Orton 1976, 59−60, 188). Today, a module for creating Thiessen polygons is embedded in almost every GIS application. The limitations of the Voronoi diagrams were clear from the first trials in concrete applications: the space that is considered is a flat, ideal space, where there are no obstacles or facilitations to movement, like rivers, roads or changes in terrain's slope. Another limitation of this analysis is that all the starting sites are evaluated as they belong to the same class of importance, so the space between a big city and a small town will be halved in two equal parts.

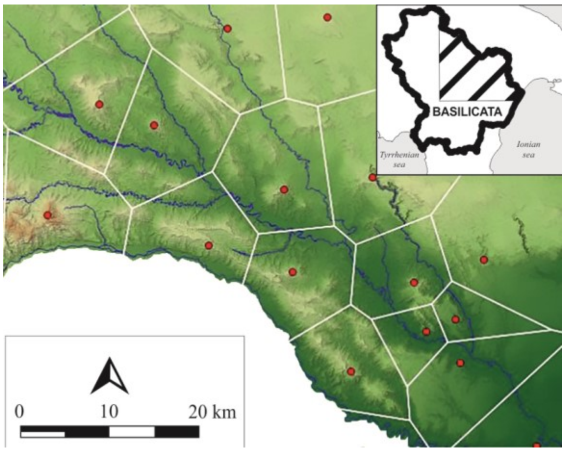

Figure 2 Bradano Valley (Basilicata, Italy). Example of Thiessen polygons creation on QGIS 1.8.

The cost allocation analysis is certainly more interesting, and it is based on the accumulated cost analysis. The accumulated cost of movement from one starting pixel to any other pixel of a raster map is expressed by a numerical value that is directly proportional to the overall difficulty to execute this movement, using the shortest path and considering, for each pixel that must be crossed, a value, usually called friction, expressing the level of resistance offered by that specific portion of territory when crossed (Gietl *et al.* 2008, White & Surface-Evans 2012). Usually, accumulated cost surfaces are just a step of more complex procedures, like the detection of the possible paths of ancient roads or the delimitation of areas that are reachable within a known amount of time. Our research group documented this in a site catchment analysis of the medieval site of Jure Vetere, near San Giovanni in Fiore, located in the central part of the Calabria region (Roubis *et al.* 2011). If we assign each pixel of an output raster map to the starting site from which movement has a lower accumulated cost, we can obtain a cost allocation analysis, which can be easily performed by some GIS applications, like ArcMap, Saga GIS or GRASS 7.

The result of a cost allocation analysis is essentially more realistic than Thiessen polygons, because the original friction raster map can be created combining many factors like the terrain's slope and elevation, the position of rivers and roads or the presence of woods, dragged fields and other elements. I want to conclude this short presentation of methods for estimating the boundaries of ancient territories considering a procedure devised by two archaeologists, the *Xtent model*.

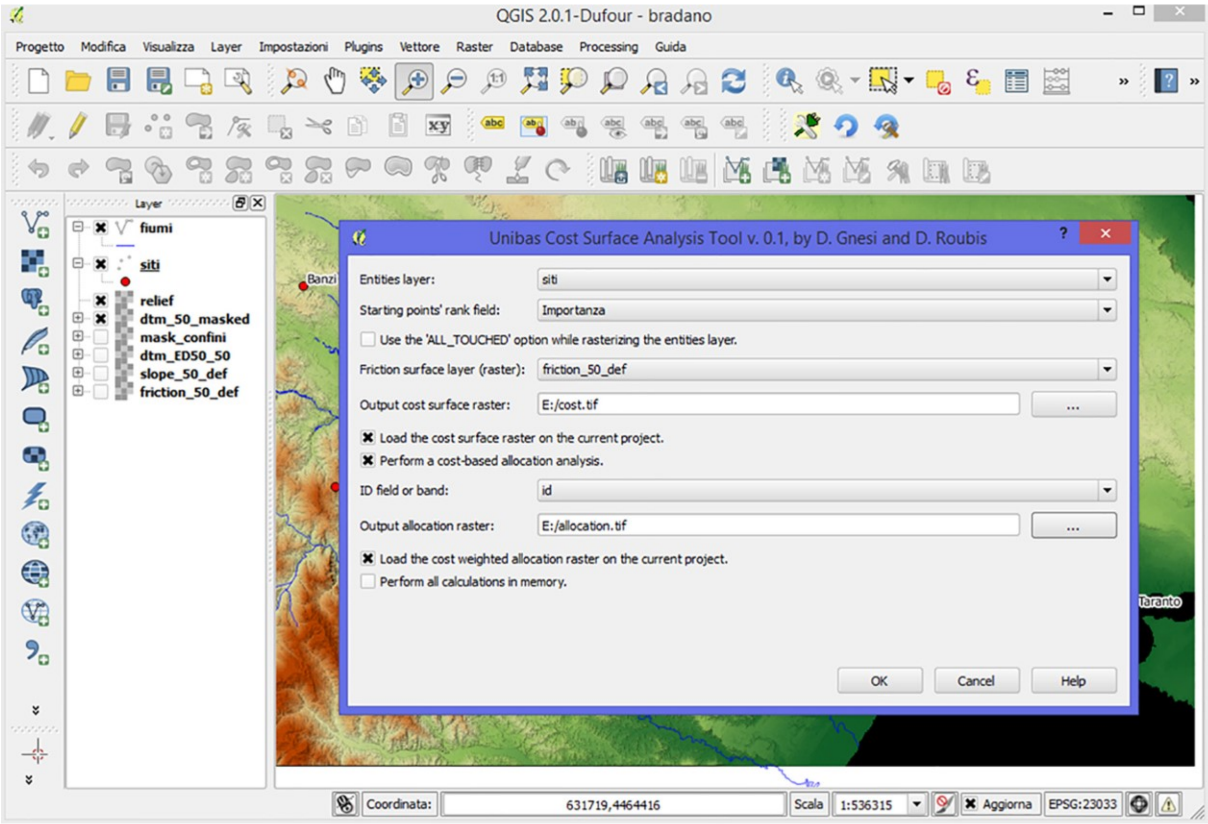

Figure 3 UNIBAS Cost Surface Analysis Plugin. Input mask.

The Xtent model was proposed in 1979 by Renfrew and Level (Renfrew & Level 1979) and an open source implementation is available for GRASS GIS (http://svn.osgeo.org/grass/grass-addons/grass6/ raster/r.xtent/description.html). In the Xtent model, the influence of a site on a specific point of territory is evaluated as:

$I = C^a - k * d$

Where:

I is the resulting influence level,

C^a is the site's importance or political "weight",

d is the distance from the considered starting site,

and k is a coefficient that can be varied in order to calibrate the ratio between the site's importance and distance. An attempt to merge the cost-based approach to the Xtent algorithm has been made by Benjamin Ducke and Peter Kroefges in 2007 (Duke & Kroefges 2008). This new implementation of the Xtent model is very appreciable because it allows the consideration of the different political or demographical weight of each archaeological site in a geographic space that is not an Euclidean abstraction. Basically, the cost-based allocation procedure and the Xtent function can be unified simply replacing, in the original Xtent formula, the Euclidean distance d with the corresponding accumulated cost value. However, in our opinion, using the Xtent formula in real cases is still counterintuitive, because that k value is a sort of magic number of uncertain origin and scale, and it can deeply change the results of the calculations.

We found it more convenient to develop a new formula, as simple as possible, to include the site's important values inside a classical cost allocation analysis, without relying on superfluous coefficients. In our first trial, we tried to redefine the entire analysis in a single procedure, altering the formulas for generating the accumulated cost values, and then allocating each pixel to the starting site with the lower accumulative cost value. The code, entirely written in Python, was included in a Quantum GIS plugin, named UNIBAS Cost Surface Analysis Tool, for which we provided a complete graphic interface designed using the Qt libraries (Fig. 3).

We modified the formulas for calculating the accumulated cost as:

$C2 = C1 + (FR1 + FR2)/ 2 \rightarrow C2 = C1 + (FR1 + FR2 / SI) / 2$

$C2 = C1 + sqrt(2)*(FR1 + FR2) / 2 \rightarrow C2 = C1 + sqrt(2)*(FR1 + FR2 / SI) / 2$ (when moving on diagonals).

The cost of the current cell, previously computed as the cost of the previous cell plus the arithmetic mean of the friction values of the two cells, is now reduced, dividing the friction of the second cell by the importance of the starting site. While this function worked well on abstract models, some defects appeared when tested on real cases. Indeed, in a model created with such a formula, the shape of boundaries calculated on long distances tends to be circular, meaning that as long as the number of iterations increases, the weight of the friction values are progressively reduced, until they become completely uninfluential. Our tool presented another important limitation: the raster of friction taken as input from the plugin must be the same for all the archaeological sites.

In order to correct these anomalies, we developed a new python library, that is callable from the QGIS python console, and which exposes two methods.

The first method takes as input data a vector layer containing the position of all the archaeological sites and, in the corresponding attribute table, two fields indicating respectively the importance of each site and a numeric unique ID. Other required inputs are a Digital Elevation Model and a raster of frictions. The procedure simply calls the GRASS "r.walk" function for each starting site. Unlike the "r.cost" function, r.walk can also consider a different speed of movement for going uphill or downhill (http://grass.osgeo.org/grass64/manuals/r.walk.html). When the accumulated cost rasters are created, a second method is responsible of making a comparison between all those files, allocating each pixel to the site from which the cost of movement is lower. Before comparing the accumulative costs of each pixel, values are divided by the corresponding importance values of the starting sites. So, the point *P* belongs to the Site A and not to the Site B if:
Acc. Cost From Site A / Importance of Site A < Acc. Cost From Site B / Importance of Site B. Commenting on this formula, we can say that the movement from an archaeological site becomes easier as the importance of the site becomes stronger. This approach has two main advantages: for each pixel the coefficients indicating the weight or importance of the starting points are evaluated only once, avoiding the creation of circular boundaries; additionally, the operator can choose to ignore the first method and to manually create the accumulated costs maps for each site, using different rasters of frictions. This facility is useful especially when historical or archaeological sources determine the ownership of roads or other kinds of communication routes by a known political center.

We are also trying to resolve the problem of avoiding "islands" of unreachable areas belonging to one site but surrounded by territories of other sites, which appear in the model when the difference of weight between two sites are too high. A solution could be to limit the assignment of a pixel to a specific site only if at least one of the surrounding pixels are already assigned to that site.
Actually, we are converting the two Python methods exposed here in scripts accessible via the Processing window of Quantum GIS 2.0, with the intent of sharing the source code. However, the workflow required in order to execute the analysis is yet very short and simple.

The first steps consists of creating the layers required as input by the analysis. These layers are: a) A raster of frictions. As we said before, friction values represent the difficulty to move through the territory; so, also if this difficulty is calculated only according to the terrain's morphology, the friction layer should not coincide with a Digital Terrain Model (DTM), but a good starting point to generate a friction layer could be the output file of a Slope Analysis. Obviously, the more accurate is the friction model, the more accurate will be the accumulated costs created over that model. b) An Esri shapefile containing points, lines or polygons representing the starting sites. The attribute table of the shapefile must contain a numeric field representing the importance or rank of the site. The choice of the method used in order to get these values is left to the operator. An objective way of obtaining these values is to consider the extension, in terms of squared meters, of each site, and to represent it in a scale of values comprised between 0 and 1 or 0 and 10. Once these layers have been created, and the Python module (a file named unibascost.py) has been copied inside the project's folder, the first step of the analysis can be launched with the following lines of code:

from unibascost import * calc_accumulated_costs (*friction_layer*, *shapefile*). The first lines imports the of all the methods contained in the unibascost.py file. The second line calls the *calc_accumulated_costs* method, which requires as parameters two strings, containing respectively the name of the layer of frictions and the name of the shapefile layer of starting sites. Calling this method will cause the creation of the raster of the accumulated cost of movement for each site. All those raster will be placed in a project's subfolder named "accumulated_costs".

The second and final step of the analysis correspond to the execution of the cost allocation analysis. The instruction needed to launch the analysis is the following one:

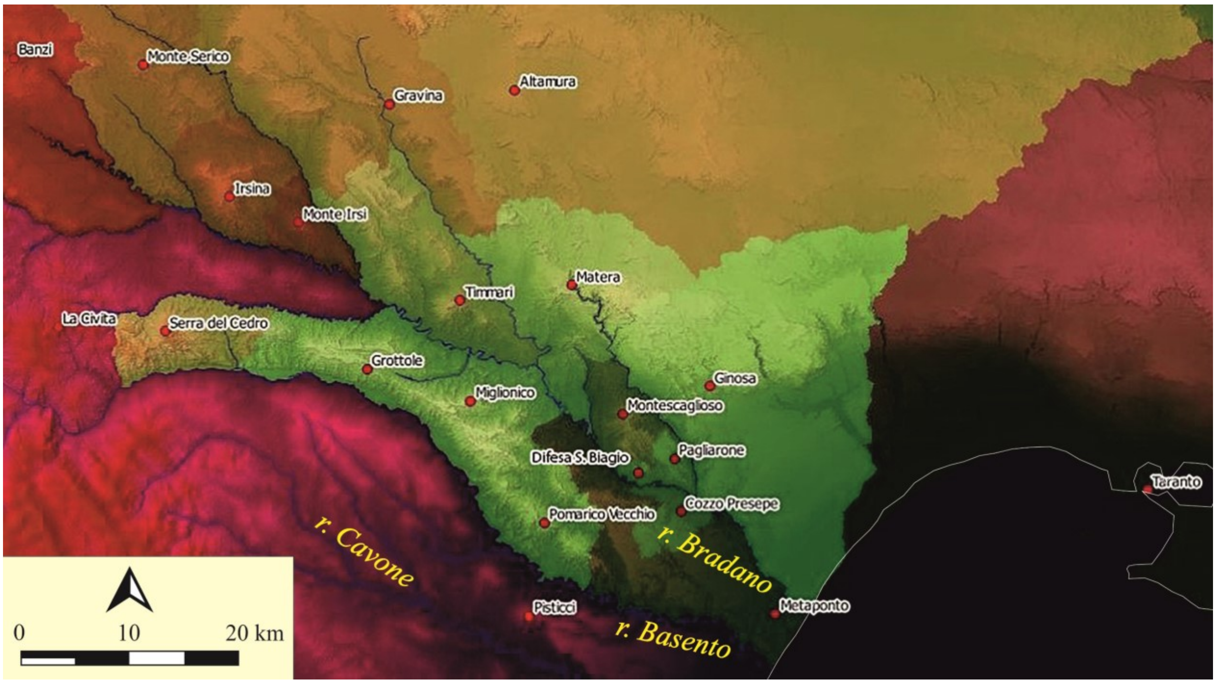

Figure 4 Custom algorithm for the cost-based allocation analysis in QGIS. Simulation created assigning a high coefficient of friction to rivers.

calc_allocation (*shapefile*, *rank_field*) where we pass to the *calc_allocation* method two strings as parameters: the name of the shapefile layer and the name of the field containing the values representing the importance of each site. We found convenient to split the analysis into these two steps because, when it is necessary to produce many outputs for testing different values of importance for the same archaeological sites, we can avoid the recreation of the rasters of accumulated costs at each trial.

Internally, the *unibascost* module uses some external libraries of function which are deployed with QGIS, and so are certainly accessible from our code when it is executed from the QGIS Python Console. In more detail, the GDAL library (http://www.gdal.org) is called to nimbly read and write data on raster files, while the adoption of the *numpy* library dramatically reduces the amount of time required by the calculations. However, we need to point out that the analysis still requires a considerable amount of time if compared to the algorithms already provided by Quantum GIS (about an hour was necessary to get the output models presented in this paper), and the reason is that Python is an interpreted programming language and the accumulative cost calculation analysis requires many instructions and many iterations (usually hundreds or thousands).

The allocation model calculated for our case study, the Bradano River valley, is based on a Digital Elevation Model of the Basilicata Region with a resolution of 20 meters downloaded from the website of the Geoportale Nazionale (our national cartographic portal – http://www.pcn.minambiente .it/GN/), while the friction layer used for this simulation contains slope data mixed with a constant value given to all rivers. The numerical parameters used to describe the importance of the various sites were derived from their physical extension: 0.5 for archaeological sites of area varying from adopted to describe the difference in terms of importance among the various sites were calculated according to their size: 0.5 for archaeological sites with a physical extension varying from 1 to 10 ha (= hamlets or agricultural villages); 1 for those varying from 10 to 80 ha (= medium and large size dominant indigenous sites); 2 from 80 ha and over (= Greek *polis*). Two simulations were provided: in the first one, a very high level of friction was given to the rivers, so the site's boundaries avoid overstepping these natural barriers (Fig. 4). In our second simulation, rivers have a lower friction values, so the site's boundaries are less influenced, except for the case of Metaponto, for which a higher friction constant was adopted for rivers, in order to make the model closer to what is known from historical and archaeological data (Fig. 5).

[D.G.]

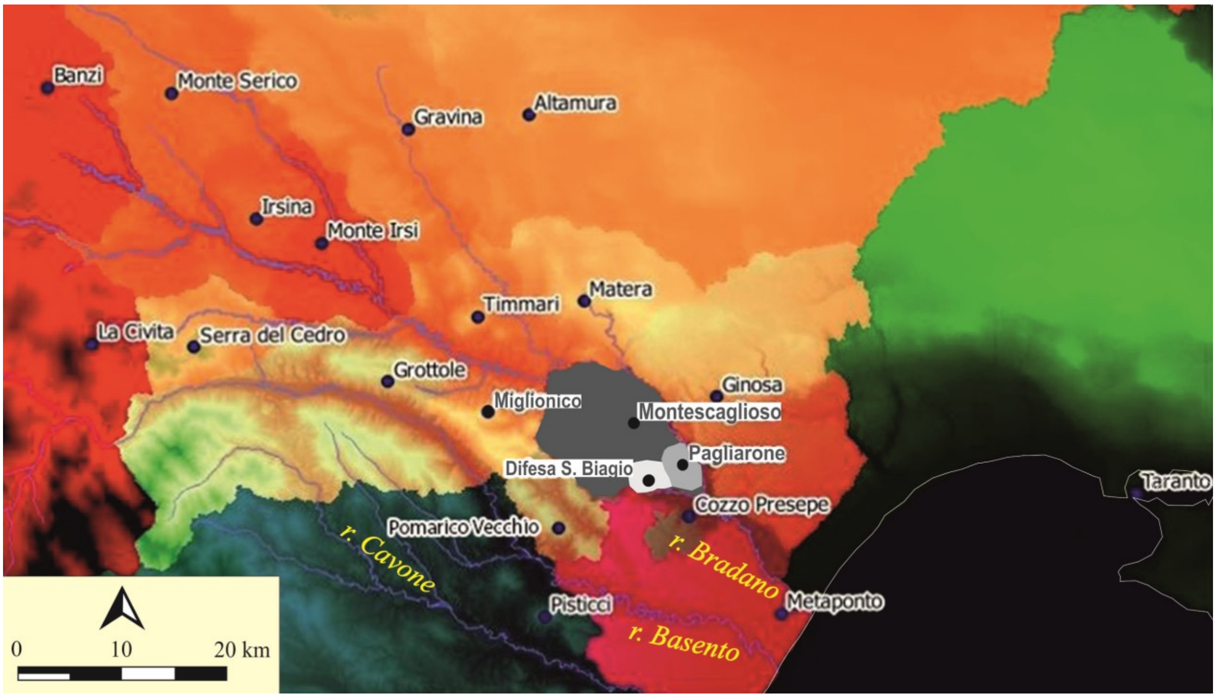

Figure 5 Custom algorithm for the cost-based allocation analysis in QGIS. Simulation created assigning a low coefficient of friction to rivers.

Conclusions

In conclusion we can say that the models described above, especially the second simulation (Fig. 5), provide an interesting tool for studying how the indigenous peoples of Montescaglioso district structured their hilly rural landscape in the Classical and Hellenistic periods. The data acquired according to the cost-surface allocation, suggest that the settlement system implied a hierarchy composed by the dominant site of Montescaglioso and its boundaries, located on the highest hilly point, and by the two medium size subordinate agricultural villages (Difesa S. Biagio and Pagliarone). These ones are structured according to the typology system of the Greek *Komai*, which were settled in the border of the colonial *chorai*. In fact, these ancient villages were located on the boundaries of two nodal points of the rural indigenous territory of Montescaglioso, near transit routes in the lower valley of the Bradano River corridor and its tributaries, to control the intensive agriculture exploitation.

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ARCHAEOLOGICAL APPROACH TO LINEAR TRANSFORMATION OF SURFACES (KRIGING, ARCGIS GEOSTATISTICAL ANALYST) AND ITS POTENTIAL FOR EXPANDING ARCHAEOLOGICAL INTERPRETATION

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Περίληψη/ Abstract

Τα Συστήματα Γεωγραφικών Πληροφοριών (ΣΓΠ) έχουν ένα ιδιαίτερο ρόλο στην αρχαιολογική ερμηνεία. Μέσα από μία μεγάλη ποικιλία τεχνικών γεωστατιστικής οι αρχαιολόγοι εστιάζουν σε εφαρμογές χωρικών μοντέλων πρόβλεψης. Ένα από αυτά, η μέθοδος Kriging, φαίνεται ότι έχει κάπως υποτιμηθεί και ότι έχει περιορισμένη χρήση. Σε αυτό το άρθρο θα παρουσιάσω εν συντομία αυτή τη στατιστική τεχνική και θα δώσω έμφαση στην πολύπλοκη φιλοσοφία πίσω από κάθε απόφαση εφαρμογής της για την ανάλυση αρχαιολογικών δεδομένων. Για τους αρχαιολόγους είναι πολύ σημαντικό το γεγονός ότι δεν χρειάζεται να χρησιμοποιήσουν πολύπλοκες παραμέτρους πρόβλεψης για ειδικές κατανομές σε συγκεκριμένες περιοχές. Οι ανθρώπινοι παράγοντες βρίσκονται πίσω από την κατανομή αρχαιολογικών χωρικών δεδομένων που κατά κανόνα είναι κανονικές (Gaussian). Αυτό σημαίνει ότι οι παράμετροι πρόβλεψης μπορεί να βασίζονται σε γραμμικό συνδυασμό των κοντινών τιμών δεδομένων. Θα τεκμηριώσω τους λόγους για τους οποίους οι μετασχηματισμοί επιφανειών με τη μέθοδο Kriging έχουν εφαρμοστεί με αυτό τον τρόπο. Επιπλέον, η παρουσίαση μου θα περιγράψει κάποια προβλήματα που εμφανίζονται από τη συσχέτιση και αυτοσυσχέτιση των αρχαιολογικών χωρικών δεδομένων και θα παρουσιάσει ενδεικτικά παραδείγματα.

Geographical Information Systems (GIS) have a special role to play in archaeological interpretation. Among the wide variety of geostatistical techniques archaeologists focus on application of spatial predicting models. One of them – Kriging - seems to remain somewhat underestimated and with limited use. In the present paper I shall present briefly this statistical technique and will stress on the complicated philosophy that stays behind any decision for its application in analysis of archaeological spatial data. Of greater importance for archaeologists is that they do not need to use complex predictors for particular distributions in specific areas. Human factors stay behind distribution of archaeological spatial data which as a rule are Gaussian in nature. This means that the predictors can be based on linear combination of the nearby data values. I substantiate the reasons that stay behind this way of application of Kriging transformation of surfaces. Further my presentation will describe some problems raised by correlative and auto-correlative features in archaeological spatial data and provide illustrative example.

Keywords: social causes, social effects, simple kriging, Moran's index, GIS

Introduction

In most cases archaeologists lack certainty in their efforts to characterize the spatial structure of archaeological evidence outlined by application of rigorous field surveys. In order to find better solution to this problem it is important to know where this uncertainty comes from. The answer to this question may vary, but it is most likely that the 'uncertainty bias' has been generated by the everyday experience of humans who live in an urban environment. Traditionally, urban centres are being considered as highly correlated structures of living areas, transportation, retail centres, hospitals, etc. Thus from a general point of view the everyday human experience coming from the life in an urbanized environment may be pointed out as responsible for generating the 'biased expectation' that the spatial distribution of archaeological evidence has to be highly structured and autocorrelated. As a corollary the assumption that comes intuitively to mind is that archaeological spatial structures should be similar to the modern urban ones and can be measured and compared with each other through formal procedures that minimize the 'uncertainty' defined by parameters such as mean value and standard deviation. This understanding has positive outcomes and generates two formal approaches to finding better ways of limiting uncertainty in the efforts for accurate characterization of archaeological spatial structures. The recent one is based on introduction of fuzzy logic into GIS for admission of the nearest neighbor (Lieskovský *et al.* 2013). The second one is that this expectation requires formulation of a general conceptual framework that makes geostatistical analyses suitable for studying archaeological spatial structures and this may be the reason why the application of geostatistical methods started early on in archaeological investigations. Hodder and Orton (1976) studied the degree of spatial autocorrelation of geographical distribution of the ratio length/breadth of Bronze Age spearheads. Kriging was applied in tasks for defining successful prediction of occurrence of archaeological sites out of an initially studied small geographic area (Zubrow & Harbaugh 1978), and in predicting the highest density of lithics in a Mesolithic site, thus contributing to a useful way of functional interpretation of the human occupation (Host 2011). These examples outline the range of application of geostatistical techniques that correspond to the interest in characterizing the spatial variation of archaeological sites, artefacts or artefacts' attributes.

This conceptual framework combined with the question how to better characterize the nature of the spatial structure of archaeological record can be further expanded by borrowing some insights from recent developments in social science. Of particular interest to this study is the notion of regionalization of the spatial structure of everyday human activities. According to it, regionalization divides human activity into autonomous and dependable human acts. The first cause the occurrence of the second type of human activities. Both types of human activities form spatially differentiated patterns (Giddens 1984, 110–126). Thus the demand for greater precision in predicting the occurrence of spatial archaeological structures combined with the novel understanding of 'social space' poses the major question explored in this study:

- Is it possible to characterize archaeological spatial structures in terms of spatial heterogeneity and spatial homogeneity so that to be able to identify and spatially characterize the social complexes that are responsible for generating highly structured archaeological spatial patterns?

In order to answer better this question, the possibility of GIS to organize large spatial data and analyze them with wide range of geostatistical techniques comes at rescue. In this respect Kriging techniques seem to constitute a focal point in the process of better characterization of the spatial variability of archaeological data. Their advantages for conceptual framing of occurrences of archaeological events within particular contexts are presented in the table below.

Kriging characteristics	Suitability for archaeological study
Helps to compensate for the effects of data clustering.	Local variation often obscures the larger regional one that may better reveal complex social mechanisms that governed the overall spatial distribution of studied data.
Provides estimate of estimation error (Kriging variance).	Provides greater coherency in the data plot despite reduction of spatial variation.
Availability of estimation error provides basis for stochastic simulation.	It provides a measure of how stable is the correspondence between the actual and the simulated surfaces.

1. Methods used in the present study

In natural sciences Kriging techniques can be applied in analyzing a wide variety of spatial phenomena caused by one or several factors. For example, in combination with ArcGIS capabilities for management of spatial data they are suitable for precise enough calculation of predicted surfaces that define the spatial distribution of air-polluted zones with differentiated risk for the populations living in the area (the example illustrating the technique in the ArcGIS Toolbox).

In archaeology and social sciences Kriging techniques alone have limited application. In these disciplines the main task is to define which spatial structures are able to generate clustered and autocorrelated social events. For these and other reasons presented in the next section the combination of three geostatistical techniques, simple Kriging, unconditioned Gaussian Simulation and Moran's Index of autocorrelation, is found suitable for the present analyses of the four datasets. The general purpose for combing the first two is to measure the degree of clustering relative to the overall spatial variation. The third one measures the degree of autocorrelation of the analyzed data.

While the above methods remain applicable to dense data with more than 30 spatial occurrences the archaeological record is not uniform and also consists of highly dispersed rare occurrences of high-status monuments and artefacts. This poses the question whether it is possible to develop a particular method that is capable of characterizing their spatial structure. The answer to this question may be formulated in the following way: by having prior knowledge about the probability model of occurrences of a given type of high-status artefacts in one geographical region is it possible to predict their chance of occurrence (deviations from the mean value) in a neighbouring geographic region? This method is illustrated by the fifth case study presented below.

Thus the combined application of these four methods covers the whole variety of archaeological spatial data. The first two case studies concern modern spatial data while the last three deal with archaeological ones. The reason for this inclusion of non-archaeological data is to better illustrate the problems associated with identification and classification of different archaeological spatial data and answer the question whether they belong to one of the two defined above categories: 'autonomous/causal' and 'dependent' social variables. Additionally, for increasing clarity and coherency of this presentation, I provide a short description of the advantages of the statistical techniques applied for characterization of the spatial structure in each case study.

1.a Assumptions for straight-line-model

Some technical assumptions have to be taken into consideration so that to be able to apply these methods correctly.

The general assumption ('assumption of existence') is that the geographic distribution of artefacts, monuments, sites, or any combination of these three categories correspond tightly to the underlying social mechanisms that act in the past and in the present and that cause their spatial emergence, distribution and preservation. For example, an experienced researcher while studying a small geographic area for the spatial distribution of megalithic structures/sites or other monuments can fairly accurately predict the existence of a new monument in the immediate vicinity of the studied area by judging from the spatial configuration of the already registered monuments. In a hypothetical experiment if ten archaeologists repeat this study in the same area but each of them approaching the zone of prediction from a slightly different direction (starts from different initial configuration of monuments) their results would be similar to the first one with small deviation from the mean value of successful predictions. From this example an assumption of existence can be made. It states that it is possible to make fairly accurate prediction of the location of new monuments provided there already exists an identified spatial pattern of sites/monuments in a given geographic region. The good results of this prediction can only be realized in combination with the overall knowledge of 'experienced' researchers (experience based on intuitive or formal knowledge about the existence of typical cases. More specifically this initial knowledge involves intuitive or abstract assumptions about the mean value and standard deviation of the monuments' spatial distribution).

The assumption for 'independence' of the occurrence of archaeological events is difficult to be made. Most of the archaeological regional structures of sites/ mouments/ artefacts are highly clustered and autocorrelated. In this situation Kriging techniques offer an advantage because they eliminate the existing trends in the initial data, 'screen off' the maximal and minimal values and eliminate the effect of small (in-group) clusters of monuments by reducing it to the effect of a single monument. Some archaeological spatial distributions may be considered as "independent" because their spatial structure does not depend on time and on other social contexts. For example, such spatial structure may be the distribution of temples in religious urban centers. Patterns like these, in typical cases, have Gaussian distribution of the mean distances between separate monuments and do not show spatial autocorrelation. However, such patterns may be considered as involving spatially independent events only within the concrete geographic context. In this sense the notion of independence characterizes the spatial structure of occurrence of past social events in a concrete geographic context while at other levels (e.g. ideological, religious, etc.) these events may form highly correlated patterns/relations that are temporary in nature.

Another important assumption is that the mean value of the studied variables has to follow a normal distribution while having equal standard deviations. Hence the estimated error of all predictive statements will also be normally distributed. The assumption is that at least for some of these variables this will hold true, while for the others the variation of the mean value will be used only as a measure for the degree of spatial heterogeneity.

2. Initial case studies, particularities of the in-put data and their analyses through simple Kriging and unconditional Gaussian simulation

The spatial examples that will be analyzed include:

(i) the distribution of populated places: all modern towns and villages in Bulgaria – data taken from ESRI-Bulgaria's 3D digital data for Bulgaria, Scale: 1:200 000 (the data are owned by NIAM-BAS);

(ii) the distribution of churches in Sofia, Bulgaria. This includes a representative sample of 50 Orthodox churches out of 113. The data are taken from the 'National Register' website (http://www.hramove.bg – in Bulgarian) of religious buildings in Sofia. To each church in Sofia the mean distance to its neighboring churches is assigned. The minimal distance is 1 km as each church has influence on religious public that overlaps with the neighbouring ones. The only exclusion is made for the main cathedral 'Al. Nevski' which is assigned the maximal value of 10 kms as it encompasses the entire perimeter of Sofia and has national religious and political importance. The towns and villages in Bulgaria are represented by their perimeters;

(iii) the distribution of rock-cut tombs in the Eastern Rhoropes Mountains, Bulgaria (Tsonev 2013);

(iv) the distribution of dolmens in the Sakar mountainous region, Bulgaria. As a measured variable the dolmens and rock-cut tombs have the mean distances to the nearest modern settlements (ibidem). This value is multiplied by 2 because of the supposition that the population during Bronze and Iron Ages was at least 2 times smaller than the present-day one.

The geostatistical techniques involved in this study include simple Kriging and Gaussian Simulation (ArcGIS Toolbox). The combination of these techniques corresponds to the above made assumptions. In its essence Kriging encompasses a class of statistical techniques for optimal spatial prediction. The optimal prediction is achieved by probabilistic predictors with standard errors that quantify the uncertainty associated with the predicted values (Krivoruchko 2012). This uncertainty or prediction error is minimized by the spatial dependence of the experimental data. Generally, this modelling answers questions such as those defining prediction of quantities of spatially distributed substances in unmeasured points situated in the neighbourhood of the already measured ones. For example, if the amount of nitrogen is measured in different locations what is its concentration in an unmeasured location situated in the neighborhood of a set of measured locations? For the estimation of the predicted surface Kriging uses a semivariogram – a function that quantifies the spatial dependence of data. It defines the weights that determine the contribution of each observed point to the prediction of new values at unsampled (not measured) locations. Hence Kriging is a smoothing interpolator.

The convenience of this technique for archaeological enquiries is the following assumption. Simple Kriging technique assumes stationarity (spatial homogeneity) of data. If so the data mean and semivariogram are the same at all locations of the data extent. In this case the best predictor is the one that uses a linear combination of the nearby data values. It is useful for studies of general patterns of spatially distributed values. In order to account for the spatial structure based on the entire variance the obtained Kriging surfaces were submitted to unconditional Gaussian simulation. This is so because the modelled spatial variation fluctuates around the expected variation as defined by the process of smoothing in Kriging. This surface is seeded by random numbers close to the measured locations and simulations are made on the base of the amount of the initial spatial variation. In these cases the number of simulations is limited to 10 because the aim is not to measure the uncertainty in measurements which requires larger number of simulations. Thus the goal of the present study is to visualize how well the simulated surfaces represent the structuring of the available spatial data in terms of their initial configuration and the specified distances assigned to the "measured" locations.

With this goal the four sets of spatial input data have been submitted to this procedure. The important value that is observed in the output of these analyses is how much the mean value of the spatial variation changes. The results from the combination of the simple Kriging with unconditional Gaussian simulation are given below.

Figure 1 represents the assessment of the spatial variation of the populated places in Bulgaria. The mean value of the overall spatial variation changes approximately 10 times. Other trials have been made involving the estimated standard deviation or trials involving the values from the minimal to the maximal spatial variation: outcomes with numbers from 0 to 9 in program's report, but the variation changes approximately within the same limits. The conclusion is that the spatial distribution of modern towns and villages in Bulgaria forms highly clustered pattern.

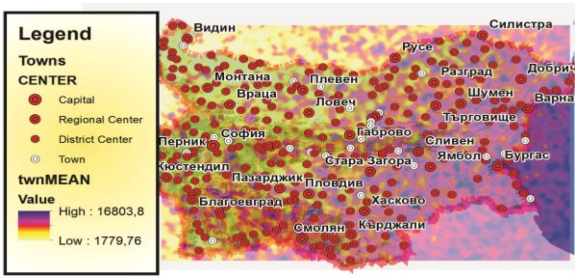

Figure 1 The assessment of the spatial variation of the populated places in Bulgaria.

Figure 2 represents the distribution of the mean value of the spatial variation of the churches in Sofia. It changes approximately 2 times. Similar trials (as in the previous case) have been made but their variation remains almost the same. This value shows formation of three uniform groups (clusters). This is due to the greater value ascribed to the main Cathedral 'Al. Nevski.

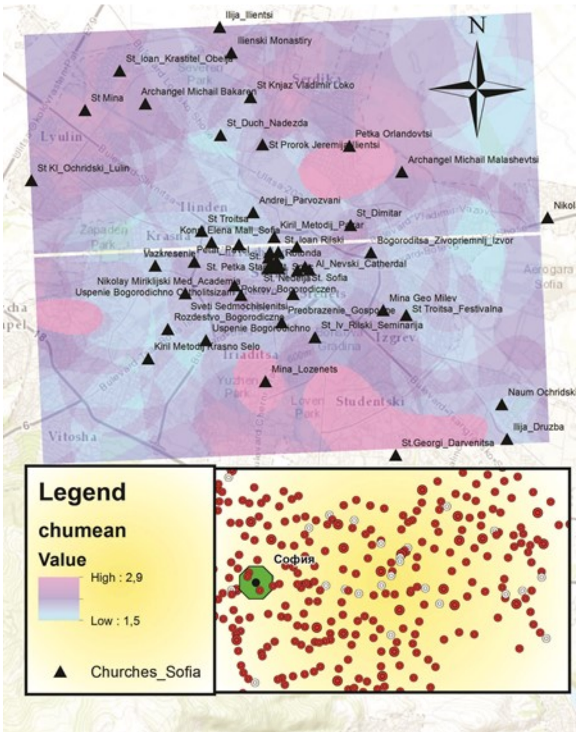

Figure 2 The distribution of the mean value of the spatial variation of the churches in Sofia.

Figure 3 shows the distribution of the mean value of the spatial variation of the rock-cut tombs in the Eastern Rhodopes Mountains. It changes between 3 and 4 times. This is moderate rate of clustering. Like the churches the rock-cut tombs tend to have local influence on populations that built and used them.

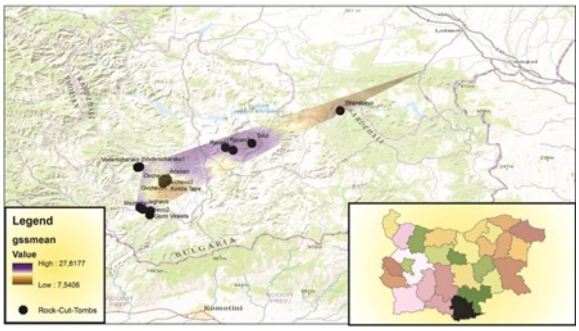

Figure 3 The distribution of the mean value of the spatial variation of the rock-cut tombs in the Eastern Rhodopes Mountains.

Figure 4 represents the distribution of the mean value of the dolmens. Their spatial variation is very low and varies between the range of 0,3–0,4 km. This means that these monuments have equal spatial importance for the local communities and may have acted as a single monument for wider communities living in a distance of 30–50 kms away from it.

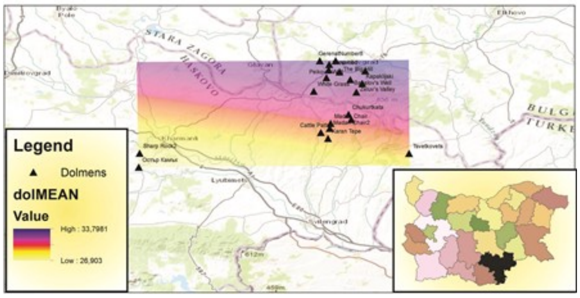

Figure 4 The distribution of the mean value of the dolmens.

The four examples show that their spatial structure varies from highly structured to random one. However, the general expectation still remains that each of the four examples should have highly autocorrelative spatial pattern. For this reason the four examples are submitted to the autocorrelation test (Moran's Index).

3. Spatial autocorrelation of the data from the four examples

Social theory defines the notion of co-habitation in the following way: 'communities of high presence-availability in all cultures are the groupings of individuals in close physical proximity to one another' (Giddens 1984, 123). Translated in archaeological terms this general definition forms the major task that aims to improve the characterization of the spatial variation of the geographical distribution of an artefact type (or artefact's attributes), or a group of monuments. The present-day experience from living intensive urban life also contributes to this kind of expectation that archaeological and modern spatial variation of humanly induced events will be highly autocorrelated. For example, the usual behavior of an individual in his/her daily walks will be to buy promoted (low price-good quality) goods from a number of closely situated shops (markets). Each individual will follow a number of independent paths (the chance of successful purchase of a promoted good from one shop instead of the opposite one). This will form a constant trend that involves most of the inhabitants of a given neighborhood that forms self-understandable structured patterns of the most successful – 'best profit' walks of autocorrelated spatial configuration that ranges between the limits of the most and the least frequently visited shops. All these examples give rise to the question: do all archaeological and modern spatial structures follow this pattern?

In order to answer this question the four input data sets have been submitted to the Moran's Index of autocorrelation (ArcGIS Toolbox – see Moran's I description of the technique).

Spatial autocorrelation is the formal property that measures the degree to which near and distant things are related. Autocorrelation literally means that a variable is correlated with itself. The simplest definition of autocorrelation states that pairs of subjects that are close to each other are more likely to have values that are more similar, and pairs of subjects far apart from each other are more likely to have values that are less similar. Groupings are examples of spatial structures that are positively correlated, whereas negative correlation may be exhibited in a checkerboard pattern where subjects appear to repulse each other. When data are spatially autocorrelated, it is possible to predict the value at one location based on the value sampled from a nearby location when using data interpolation methods. The absence of autocorrelation implies that data are independent but, as it is pointed out above, this independence is understood to be valid only within the concrete geographic context.

Moran's I takes the form of a classic correlation coefficient in that the mean of a variable is subtracted from each sample value in the numerator. This results in coefficients ranging from (–1) to (+1), where values between (0) and (+1) indicate a positive association between variables, values between (0) and (-1) indicate a negative association, and (0) indicates there is no correlation between variables. In all the tests the matrix of weights between all involved in study locations compares the sum of the cross-products of values at different locations, two at a time weighted by the inverse of the distance between the locations.

The results of the four tests are summarized in table forms taken from the standard ArcGIS Toolbox 'Spatial Autocorrelation Report'. They are presented as follows:

Table 4		**Table 5**	
Moran's Index:	0,181598	**Moran's Index:**	0,018515
Expected Index:	-0,000205	**Expected Index:**	-0,020408
Variance:	0,000026	**Variance:**	0,002703
z-score:	35,850933	**z-score:**	0,748658
p-value:	0,000000	**p-value:**	0,454063

Table 4: Populated Places in Bulgaria. Moran's I: Given the z-score of 35.85, there is less than 1% likelihood that this clustered pattern could be the result of random chance. **Table 5**: Churches in Sofia. Moran's I: Given the z-score of 0.75, the pattern does not appear to be significantly different from random.

Table 6		**Table 7**	
Moran's Index:	-0,029281	**Moran's Index:**	-0,033722
Expected Index:	-0,062500	**Expected Index:**	-0,052632
Variance:	0,019131	**Variance:**	0,007007
z-score:	0,240166	**z-score:**	0,225901
p-value:	0,810202	**p-value:**	0,821278

Table 6: Rock-cut tombs. Moran's I: Given the z-score of 0.24, the pattern does not appear to be significantly different from random. **Table 7**: Dolmens. Moran's I: Given the z-score of 0.23, the pattern does not appear to be significantly different from random.

Table 4 presents the results of the autocorrelation test of all towns and villages in Bulgaria. As it has already been noted the results from simple Kriging and unconditional Gaussian Simulation of towns and villages show marked spatial structuring. The autocorrelation is also very high.

The simple Kriging and Gaussian simulation also produced moderate spatial groupings of the churches in Sofia and the rock-cut tombs (Fig. 2, 3). The intuitive expectation is that these data will be autocorrelated. But they are not and fall into the random section of the diagram (Table 5, Table 6).

Table 7 shows that the spatial pattern of dolmens is not autocorrelated too.

These results only show that there must be some social mechanisms that are responsible for the spatial patterns of the analyzed above examples in terms of differentiating them into two categories: spatially homogeneous and spatially heterogeneous ones.

4. Model for assessment of spatial occurrences of high-status artefacts

In order to test how much these social mechanisms influence the spatial patterns of archaeological and other social phenomena it will be reasonable to model the occurrences of highly dispersed, independent archaeological spatial data that consist of high-status artefacts/monuments. A question arises: where to find a representative sample of such highly dispersed archaeological spatial data. It is difficult to come across such data as they have to possess some specific properties. Among them the most important one seems to be to look for artefacts with well-identified source(s) of provenance of the valuable materials they are made of. The second property requires looking for artefacts that symbolize similar social meanings at different geographic regions. This requirement is necessary because the most likely scenario is that the social mechanisms that stay behind production and distribution of such artefacts will not be valid to the same degree as when these artefacts occur in regions that lie at more than 1000 kms away from their production center. Additionally it will be correct to make the conjecture that the chances of occurrence of such artefacts in their peripheral zones of circulation will follow the probability distributions used in explanation of 'game models'.

In line with these considerations the best candidate that meets these requirements is the distribution of 'jade' Alpine axeheads and their imitations (axes made of diorite, amphibolite and serpentinites) in the Balkans (Pétrequin *et al.* 2012b, 1231–1310). The two regions which I have better knowledge about the distribution of these artefacts are the areas to the southeast and to the northeast of the Lower Danube. The question that arises may be formulated in the following way: if in the region to the southeast of the Lower Danube out of 10 trials there are 2 successes (two axes have been identified as made of Alpine 'jade' or other valuable rocks) than what will be the chances of success in the region situated to the northeast of the Lower Danube. Both regions are "peripheral" to the distribution of the Alpine 'jade' axes and the expectations will be that they would have had similar occurrences following Binomial distribution model. In the frame of this conceptual framework it is necessary to correct this expectation allowing for the presence of regional differences as the Lower Danube may form a boundary – not only physical but also in human beliefs, rituals and material cultural expression. In this case the question should be reformulated in terms of what is the probability for deviation from a certain mean number of occurrences of such artefacts – chances of occurrence of less or more than 3 Alpine 'jade' or made of other valuable rocks axes.

The answer to this question comes straight from tabulating the probabilities of expected occurrences of Binomial distribution model and comparing them with the real artefacts that have been identified. Thus the probability of occurrence of 2 'jade' axes out of 10 trials can be modeled by Binomial distribution:

$$P_k^{(n)} = P\left(X^{(n)} = k\right) = \binom{n}{k} p^k q^{n-k}$$

Where n is the number of trials, k is the number of successes, and $q = 1 - p$.

In this case n=10, $= \frac{2}{6} = \frac{1}{3}, q = 1 - p = \frac{2}{3}$.

$$P_k^{(10)} = \binom{10}{k} \left(\frac{1}{3}\right)^k \left(\frac{2}{3}\right)^{n-k}$$

The probabilities are presented below.

$P_0^{(10)} = 0{,}0173415$
$P_1^{(10)} = 0{,}086707$
……
$P_3^{(10)} = 0{,}26012$
…..
$P_6^{(10)} = 0{,}056901$
…..
$P_{10}^{(10)} = 0{,}0000169$

The mean value is $\alpha_1 = EX = np = 3{,}3\overline{3}$ $\sigma = \sqrt{EX} = 1{,}83$. Of interest is what are the deviations a for $k = 3$, mean value $3{,}3\overline{3}$ relative to the neighboring values $|k - k_{EX}| \leq a$, $k_{EX} = 3$ (symmetric distribution $k_{EX} = EX = \alpha_1$).

$P(|k - k_{EX}|) \leq a$

The values are given in the table below.

Deviation a	k	P
0	3	$P_{(3)} = 0{,}26012$
1	2…4	$P_{(2)} + P_{(3)} + P_{(4)} = 0{,}68281$
2	1…5	$P_{(1)} + P_{(2)} + \cdots P_{(5)} = 0{,}90607$
3	0….6	$P_{(o)} + P_{(1)} + \cdots P_{(6)} = 0{,}98031$
4	0….7	$P_{(0)} \ldots + P_{(7)} = 0{,}99657$
5	0….8	$P_{(0)} \ldots + P_{(8)} = 0{,}99962$
6	0….9	$P_{(0)} \ldots + P_{(9)} = 0{,}99996$
7	0...10	$P_{(0)} \ldots + P_{(10)} = 1{,}0000$

The maximal deviation from the mean value is 7 which corresponds to the actual number of identified true Alpine 'jade' axes. If the 'imitations' (axes made of other valuable rocks such as diorite and amphibolite) are taken into consideration the typical deviation from the mean value is 1 axe. This may be considered as the 'typical' deviation where the chances of occurrence of 2, 3 or 4 axes in one archaeological collection equals to 0, 68281 which indicates high probability of occurrence.

5. Cause-Effects interactions

In social science the notion of regionalization: division of space of ordinary routines of social life into front and back regions offers the conceptual framework for dividing some of archaeological spatial data into ones that cause and the other that depend on the actions of the causal variables. Of particular interest for this study is the further development of this notion by the association of back regions with autonomous ritualized social actions while the front regions are associated with social actions that act on the social surface and hence it is possible to conclude that they depend on causes (situated in the back region) responsible for their appearance (Giddens 1984, 127).

A question arises as to how can this theoretical framework be applied to better understand the spatial characteristics defined in the case-studies presented above? In order to give satisfactory answer to this question I will provide an artificial example of modern highly clustered and autocorrelated spatial data and their functional link to their social causes which are spatially autonomous, not clustered and not autocorrelated. For example, a farmer who grows crops and wants maximal production of wheat has to fertilize his/her field with chemical fertilizers, spray the crops with chemical substances against insects, diseases, weeds, etc. In the field, as a result of his/her activities over several years, there will be highly clustered and spatially autocorrelated presence of areas with soil erosion, remains of particular insects, weeds associated with production of wheat, and chemically polluted zones. The social causes responsible for these spatial data come from the nearby town where the farmer either lives or attends frequently. In the town market for crop producers he/she meets his/her competitors; in a bank the farmer takes loans and is encouraged to increase crop production; in the church the farmer prays for high crop yields. Thus the various social causes in an urban environment such as the market for crop producers, banks, churches, a school for agricultural management, etc. are spatially independent from one another (situated at almost equal distances from each other). They may form loose groups with no spatial autocorrelation among them. The effects of their activities, however, are visible in the highly structured and autocorrelated spatial data in the farmers' fields of crops.

The applied analytical geostatistical procedures as well as the overall conceptual framework of existence of autonomous and dependent social spaces defined by the social science permits to make a precise classification of the above presented case-studies in terms of cause-effect relationships. I will present the archaeological interpretations of each of these examples.

5.a Particularities of the spatial distribution of alpine jade axeheads in the eastern Balkans

Of particular interest to this analytical framework is the distribution of 'jade' axes in the region situated to the northeast of the Lower Danube. The probability of occurrence of these axes approximates Binomial distribution. The mean value of their spatial distribution becomes necessary for the "rough" estimation and prediction of occurrence of the studied social events. Although "rough" this estimation makes possible to assess the spread of the regional significance of the social values of a small number of true jade axes found so far. They may be categorized as social causes that have the potential to generate highly structured in space and autocorrelative patterns of axes made of other valuable and imported rocks. Thus both spatial structures (true 'jades' and 'imitations') establish a semantic link between them because they are governed by a hierarchy of social structures and values. For example, if in the primary zones of production and distribution 'jade' axes may be considered as a symbol of the process of emergence of social inequality (their spatial patterns form Gaussian distribution in the form of a geographical gradient with pronounced center), (Pétrequin *et al.* 2012a, 544–547) then in the peripheral zones they may correspond to many different social mechanisms of substitution of ritual practices, transmission or exchange of valuable objects.

Also I would like to stress the fact that in this study I use the term 'peripheral zones' under the condition that Copper Age communities in the northeast Balkans are not understood as primitive or peripheral to a highly developed center. Through this technical term I designate that the sparse distribution of some high-status artefacts may come as a result of the process of substitution or altering of particular ritual associated with this artefact type.

The other four examples fit well to this cause-effect conceptual framework.

5.b Particularities of the spatial distribution of populated places in Bulgaria

The highly clustered and autocorrelated pattern of spatial distribution of Bulgarian towns and villages places it on the side of the social effects (dependent spatial structures). Indeed, the effects of all aspects in the history and geography of this region are summarized in this spatial structure. The presentation and explanation of all social causes that generate this spatial structure goes beyond the present study. Suffice it to say that behind each town or village a number of social causes can be identified that historically defined its exact geographical location.

5.c Particularities of the spatial distribution of churches in Sofia

The spatial structure of the churches in Sofia suggests that they as a group of monuments have to be placed on the side of social causes. Their spatial pattern is weakly clustered but not autocorrelated. This spatial structure, however, cannot be considered as an exemplary one and that it will repeat in most of the other urban centers. The reason for this is that Sofia was a central religious place in the Balkans since the late Roman Empire. Religious centers take the form of permanent spatial patterns that are capable of generating various forms of social events. Even Ottomans respected Sofia as important spiritual place for their Christian subjects and turned the town into administrative center of their territories in the Balkans. Under their rule the town remained religious center for Christians which probably is the reason why Sofia did not develop into commercial or industrial center. Later this status played significant role in turning Sofia into a capital of Bulgaria. In competition with other towns Sofia overpassed much better developed commercial and industrial centers in north and later in south Bulgaria. The major result of this case-study is that the distribution of churches (or temples of other religion) within a religious urban center has to be expected to form locally independent and not autocorrelated spatial patterns.

5.d Particularities of the spatial distribution of rock-cut tombs

The spatial structure of rock-cut tombs from Bronze and Iron Ages is moderately clustered just as the spatial pattern of the churches in Sofia. Both examples, however, remain not autocorrelated. The pattern of the rock-cut tombs is mutually exclusive with that of dolmens. The rock-cut tombs group themselves into small clusters which may signify their local use but preserve also the overall spatial structure of a center of ritualized human activities. This is in contrast to the nearby towns and villages which, as it has been seen from the example of populated places in Bulgaria, exhibit highly clustered and autocorrelated spatial pattern. Thus rock-cut tombs may be classified as a social cause that has the potential to generate settlements and other human activities around them.

5.e Particularities of the spatial distribution of dolmens

The spatial distribution of dolmens is quite similar to that of the churches in Sofia. As a group of monuments they were able to influence human rituals and beliefs over significant distances. This is also visible from their complete absence in the "peripheral zones" of their distribution (North - western Bulgaria). This fact also suggests the specificity of these monuments as expression of human beliefs and ritual practices and classifies them among social causes that were able to generate particular human activities around them.

Conclusions

The results from the analyses of the above examples help to better understand the previously established by social science categories of structuration of social systems both in the past and in the present. They provide fairly good formal illustration of the backstage and front-stage human activities or between autonomous (independent) and dependent social variables. It should be noted that this distinction is not absolute and while a set of social variables has the potential to generate a set of spatially dependent social variables they, in turn, may come as a result of influence exerted by another set of independent variables. Also it should be noted that the relationship between independent and dependent social variables does not lead to formation of strict hierarchies. Rather within a given set of autonomous (independent) social variables temporary combinations are possible that dominate for a certain period of time and then collapse and become replaced by another temporal correlative structure.

The advantage of this approach becomes even more visible when combined with better understanding of the nature of spatial patterns of high-status archaeological monuments and artefacts. The fact is that the spatial distances between the autonomous (independent) social variables may be considered as functionally related to their relative social importance. If local variation is ignored as in Kriging than it becomes clear that each monument is built at a certain mean distance from the other monuments in a given region.

In the cases of spatial structures that consist of social causes the distances that separate them will follow Gaussian distribution. In turn, Binomial distribution will be more appropriate for description of spatial variation of socially dependent variables. In both cases other distribution models with pronounced mean value may be used. These models are necessary in order to characterize the spatial variation and make predictions about probability of occurrence of artefacts and other social events.

Thus interpreted in slightly different terms the results show the importance of deviations from the mean value as a measure of systems interaction. 'Social causes' form spatially limited networks with relatively autonomous local centers. They, however, have the potential to generate social effects in the form of propagation of spatially grouped and autocorrelated interactions. It is this relational approach to the two different categories of social events in terms of the variation of the spatial patterns they form that opens up new possibilities for their research not only as formal entities but also as active social agents that shape the complex behavior of multi-level adaptations of societies in the past and in the present.

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ENHANCING EXCAVATION ARCHIVES USING 3D SPATIAL TECHNOLOGIES

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Περίληψη/ Abstract

Πρόσφατες εξελίξεις στις χωρικές τεχνολογίες προσφέρουν νέες ευκαιρίες για την ψηφιακή αναβάθμιση υφιστάμενων ανασκαφικών αρχείων. Η παρουσίαση περιγράφει μεθόδους και τεχνικές για τη μετατροπή της χωρικής πληροφορίας που καταγράφεται στα αρχεία αυτά σε τρισδιάστατες (3Δ) αναπαραστάσεις. Προς αυτή την κατεύθυνση, τα Συστήματα Γεωγραφικών Πληροφοριών (ΣΓΠ) μπορούν να συμβάλλουν στις διαδικασίες γεωμετρικής μοντελοποίησης, στην ενσωμάτωση και τη συνολική διαχείριση χωρικών δεδομένων που έχουν παραχθεί χρησιμοποιώντας διαφορετικές τεχνικές, καθώς και στη μεταγραφή των πληροφοριών που διατηρούνται σε διάφορα μέσα τεκμηρίωσης, είτε αναλογικά είτε ψηφιακά. Το αποτέλεσμα των συναφών εργασιών διαμορφώνει νέους δυναμικούς τρόπους αλληλεπίδρασης με το περιεχόμενο ενός ανασκαφικού αρχείου στο πλαίσιο ενός τρισδιάστατου χαρτογραφικού περιβάλλοντος, επιτρέποντας την καλύτερη κατανόηση των στρωματογραφικών σχέσεων και τη μελέτη της διαφοροποίησης στο χώρο και το χρόνο. Περαιτέρω τεχνικές για την ομαδοποίηση των δεδομένων και την ποσοτική ανάλυση μπορούν να διευκολύνουν διεργασίες εξαγωγής πληροφορίας. Τα παραδείγματα χρήσης προέρχονται από πρόσφατες εργασίες στις προϊστορικές θέσεις της Τούμπας Θεσσαλονίκης και της Αγίας Τριάδας στην Κάρυστο.

Recent advances in spatial technologies present new opportunities for augmenting existing excavation archives. This paper outlines methods and techniques for the transformation of spatial information recorded in these archives into 3D representations. Towards this end, the use of GIS can assist the modelling process, integrate spatial data produced using different modelling procedures and support the transcription of information held in diverse documentation means, both paper-based and digital. The outcome of such modelling exercises can enable new dynamic ways of interacting with an existing excavation archive within a 3D cartographic environment, thus allowing the improved understanding of stratigraphic relations and spatiotemporal patterning. Additional techniques for data grouping and quantitative analysis can facilitate further information extraction processes. Examples are used from recent work on the prehistoric sites of Thessaloniki Toumba and Ayia Triada Karystos.

Keywords: 3D modelling, visualisation, GIS, excavation archive, intra-site, Ayia Triada Karystos, Thessaloniki Toumba

Introduction

This work stems from a research project concerning excavation data recording and management that led to a complete 3D digital workflow using GIS technology for the prehistoric excavation of Paliambela Kolindros in Greece (Katsianis *et al.* 2008, Τσιπίδης *et al.* 2012). In the process it was recognised that the methodologies and tools developed, apart from assisting digital documentation in ongoing projects, provided an opportunity to further elaborate existing excavation archives in paper or in semi-digital form. In the Mediterranean region excavation research in the last century has generated many large datasets - some of them are finalised, while others are still being developed - that can be digitised, re-modelled and re-investigated with a view to extract new information or allow their correlation with other more recently compiled research data.

1. State of research

Work in this line of research has grown lately, as it has been realised that new technologies generate new opportunities to interact with existing data in new interesting ways. Originally, emphasis was placed on the digitisation of archaeological datasets and the creation of large data archives that would integrate archaeological information with a view to preservation and dissemination, usually on a national scale through central access portals (e.g. National

Monuments Catalogues) and more recently at an international level (e.g. Europeana) (Kintigh 2006). Gradually, attention has shifted from preservation and diffusion to data re-use giving the opportunity to look at old data with new ways. With respect to the use of GIS as a platform for the unification of individual spatial datasets, landscape studies provided the obvious point of departure, to be followed by a progressively increasing attention to intra-site research (Allison 2008).

Over the past few years a number of studies have manifested the suitability of GIS in intra-site applications (e.g. Losier *et al.* 2007, Ducke & Suchowska 2010, Katsianis 2012). GIS can assist the modelling process, integrate spatial data produced using different modelling procedures and support the transcription and management of information held in diverse documentation means, paper-based or digital. The outcome of such modelling exercises can enable new dynamic ways of interacting with an excavation archive within a 3D cartographic environment, thus allowing the improved understanding of stratigraphic relations and spatiotemporal patterning. Data from post-excavation lab studies can also be integrated allowing their collation with fieldwork documentation. Further techniques for data grouping and quantitative analysis can facilitate information extraction processes. Through an informal and almost intuitive analysis of a cartographic display, new observations can be directly extracted.

Recurring problems need to be tackled though, biggest of which is the extraction of information from essentially 2D documentation and the representation of features in 3D. The latter is a field of research that has witnessed rapid developments in both data capture and data manipulation. Laser scanners and photogrammetric procedures have facilitated the rapid and voluminous 3D spatial information collection, while 3D modelling software techniques are currently being implemented in many GIS software extending their 3D capabilities (McCoy & Ladefoged 2009, Wulf *et al.* 2013). Unfortunately, spatial data precision and coverage are precisely the main shortcomings of legacy datasets. The integration within a GIS environment of spatial documentation dating back to just a decade ago can prove to be very challenging, especially if 3D representation is concerned.

2. The case studies

Towards this end, data collections from two excavation projects with different characteristics and recording strategies were used as case studies. The exercise revealed a number of factors that can influence the process of extracting and re-modelling relevant spatial information into 3D features. It also demonstrated the potential of enhancing the representation of an excavation archive using GIS tools as a visual medium to re-visit the documentation of a site.

The process employed ArcGIS 10 by ESRI as the underlying software platform for spatial data modelling and integration. The visualisation environment of ArcScene facilitated the representation and visual exploration of the resulting 3D spatial features. In both cases, all information that resulted from the transcription of available documentation was integrated into a geodatabase structure containing feature, object and relationship classes. The modelling process was complemented with SketchUp for producing complex geometrical features, such as excavation units.

2.a Thessaloniki Toumba excavation archive

The prehistoric settlement of Toumba is located in the eastern part of the city of Thessaloniki and was populated for the most part of Bronze and Early Iron Age. Successive rebuilding on the same place resulted in a tell-site almost 23 meters high, counting at least 14 consecutive building phases that correspond to more than 1,700 years of settlement life. Its excavation by the Aristotle University of Thessaloniki began in 1984 and continues until today, bringing to light important archaeological discoveries about the social organisation, the daily life and the economy of the inhabitants.

In recent years (2006–09) remains of two large mudbrick buildings (Buildings E and B) have been revealed to the east of the large building complex (Building A), which occupies the part of the excavated area at the top of the mound, incorporating significant storage facilities. With their study currently underway and the excavation sector expanding to surrounding areas, it was thought that the efficient representation of the archaeological deposits and findspots in 3D could assist stratigraphic reconstruction and phasing based on pottery (Ανδρέου & Ευκλείδου 2010) (Fig. 1).

The archaeological project at Thessaloniki Toumba has been an excavation laboratory since its outset, as it placed an emphasis on standardised fieldwork procedures, such as context based digging and pro-forma logbooks, which eventually became the norm in most archaeological projects in Northern Greece. Further attention was channeled towards the integration of digital methodologies to assist on-site spatial recording (Patias *et al.* 1999), data organisation (Hadzilakos & Stoumbou 1996) and feature representation (Kotsakis *et al.* 1995, Koussoulakou & Stylianidis 1999). However, these efforts have not reached a 3D data management platform that would integrate all available documentation.

Figure 1 The prehistoric settlement of Thessaloniki Toumba. View of the modelled excavation sector - depicted in yellow in the top right plan (Thessaloniki Toumba excavation archive).

We decided to use data from the more recent excavations as a case study, before embarking on a more ambitious project to digitise the entire archive accordingly. Data from the 2006–2009 seasons can be found in a range of media. With the exception of free-text comments and context sketches, all information held in pro-forma documents supporting fieldwork recording has been regularly entered into an MS Access database. Film and digital photography were both used regularly during the excavation process, while spatial recording included total station surveying, which resulted in individual measurements entered in the logbooks and 2D CAD drawings.

To accommodate the excavation archive for integration in a 3D GIS environment, we began by selecting the data categories that could be visualised in 3D. In this respect, findspot coordinates were used to create a 3D point theme of the excavation finds. We then moved onto modelling the actual excavation deposits. In Toumba, excavation proceeds by defining excavation units, i.e. subdivisions of distinct deposits. The measurements defining the limits of each excavation unit were used to create closed b-rep objects through a custom programming routine that calculates their geometry (Tsipidis *et al.* 2011). Each of these features can be joined to the respective attribute table and visualised according to different properties, such as by material type in the case of artefacts or munsel colour values in the case of units (Fig. 2).

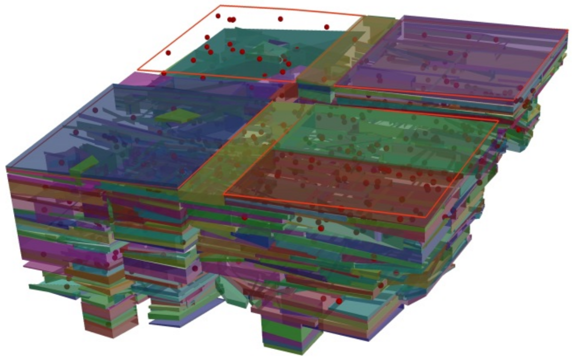

Figure 2 Modelling of finds as 3D points using X, Y, Z coordinates and excavation units as b-rep objects (shown in transparency) using measurements defining top and bottom unit limits.

The creation of surfaces employed data recorded in the CAD drawings. Each drawing was imported as a separate file in the GIS and re-positioned to the correct location. In cases where only few depth values were noted on the drawings, the situation was amplified by extracting measurements from the relevant excavation units using the database records and photographs documenting the excavation process. Breaklines were additionally digitised to take into account abrupt changes in elevation (e.g. from the presence of a wall). The combination of the above allowed the generation of TIN (Triangulated Irregular Network) surfaces approximating the original topography. Line features in each CAD drawing were converted into individual 3D line themes by receiving Z values from the corresponding TIN.

To complete the reproduction of the trench topography, section drawings were georeferenced using measurements at their corners. Following the creation of TINs using these coordinates, each section drawing was draped over its matching TIN and projected in its actual position and size (Fig. 3).

The modelling procedure was complemented with the generation of the terrain of the entire mound from survey data, in order to place all archaeological features within the excavation grid and the immediate surroundings (Fig. 4). The establishment of a common spatial background opens up the prospect of integrating all excavation data, not only from the current university project, but also from the repeated rescue excavations conducted by the Archaeological Service at the lower part of the mount.

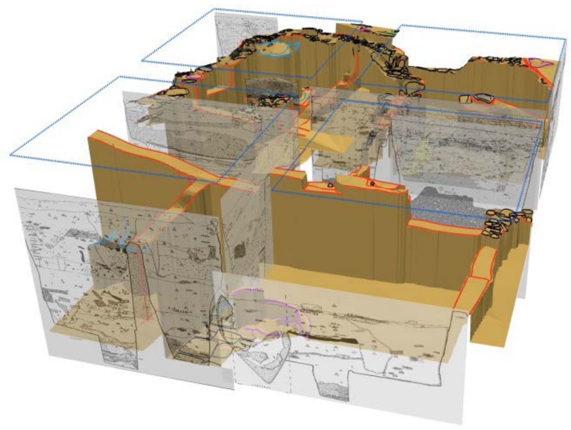

Figure 3 Modelling of section and plan drawings.

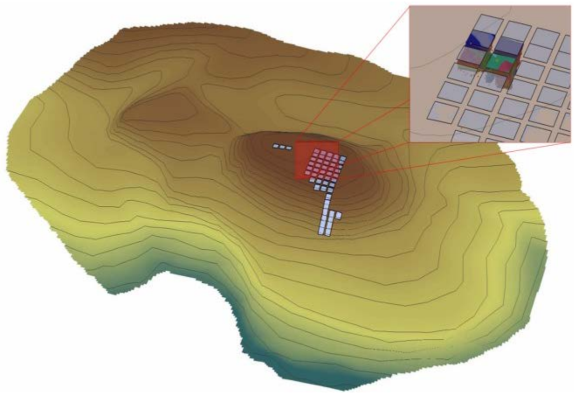

Figure 4 Integration of modelled data within excavation grid and wider landscape features.

2.b Ayia Triada Karystos excavation archive

The other example is based on the cave of Ayia Triada, which is located in the vicinity of Karystos, Southern Euboea. The excavation is a project conducted by the Ephorate of Palaeoanthropology-Speleology of Southern Greece (EPSNE) in collaboration with the Southern Euboea Exploration Project (SEEP) archaeological team. The cave was excavated for four consecutive seasons between 2007 and 2010 (Mavridis & Tankosić 2009).

Excavation concentrated mainly in the eastern chamber, where a total area of ca. 15 m^2 was excavated in small trenches each covering an area of ca 1x1 m^2 (Fig. 5). Most material is retrieved from undisturbed cultural layers and dates to three chronological periods: Late Neolithic (LN), Final Neolithic (FN), and Early Bronze Age (EBA). The case study is directed towards the exploration of spatial data patterning in relation to mortuary ritual activities of the EBA phase and cave taphonomy (Mavridis & Tankosić forthcoming *a-b*, Katsianis et al. forthcoming).

With the exception of digital photo capture, recording was handwritten and transcribed in the daily logbook held in a word processor every evening. X and Y coordinates were measured from the sides of each trench, while height measurements were taken using a theodolite. All measurements were transferred to spreadsheets in the evening. Drawings were sketched in graph paper and included a set of height measurements for the documented surface or section.

Figure 5 Excavation at the Ayia Triada cave (Photos by F. Mavridis & Ž. Tankosić: Ay. Triada excavation archive).

Initially, we focused on mapping the cave topography. We began by the establishment of a local grid, the orientation of the trenches in a North-South axis and the modelling of the interior cave topography using data from the survey that followed the completion of the excavation activities. This resulted in a 3D reconstruction of the chamber floor prior to investigation which included the exact location of the trenches (Fig. 6).

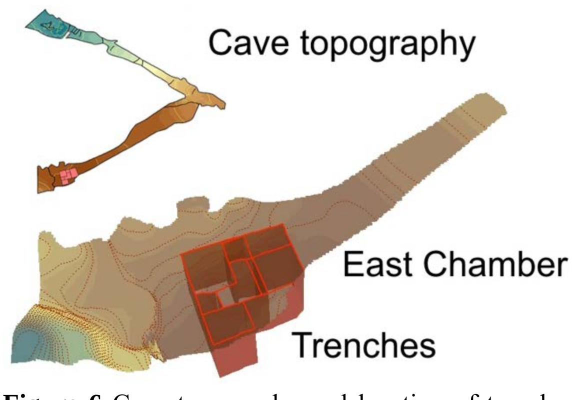

Figure 6 Cave topography and location of trenches within East Chamber (Survey by T. Chadzitheodorou, EPSNE).

Using the spreadsheets, the X, Y coordinates of all individual finds were plotted in the GIS. Z values were used to convert them into a 3D point theme. Theme contents can be joined to their respective attribute table and be displayed according to different artefact properties, such as by material type.

Measurements recorded at the corners and the centre of each context were used to create closed 3D polygon meshes. These are rather crude representations of the extents of each deposit, but they can give an idea about the volume of each layer and also provide an efficient way to represent variation in terms of layer content values (e.g. soil texture values) and bulk find quantities (e.g. pottery weight). The construction procedure involved the formulation of the top of each layer in ArcGIS as TINs and their ensuing combination in Google SketchUp as closed polygons representing the volume of each layer. The final geometric objects were re-imported in ArcGIS as multipatch objects and linked to attribute information (Fig. 7).

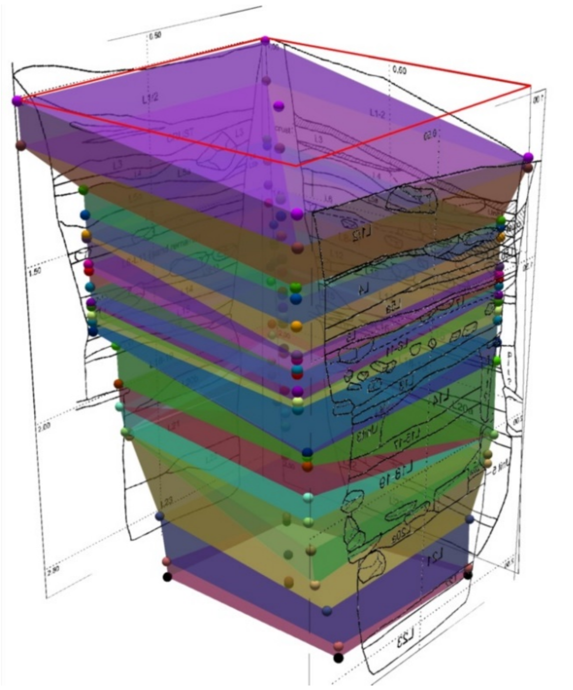

Figure 7 Modelling of excavation layers as closed polygon meshes. 3D points indicate layer corners and centre measurements.

The original plan drawings had to be scanned and georeferenced. Height measurements noted on the drawings were used to create a Digital Elevation Model (DEM) of the surface for each drawing. Breaklines in the topography were digitised on the plan and used in the interpolation procedure, so as to ensure that sharp relief variations would be indicated in the final end-product. Each drawing can be visualised in 3D after receiving height values from the resulting DEM. A similar procedure was used in the case of the section drawings, which were georeferenced and draped over a TIN.

The textured DEM of each drawing can be used as the background to digitise features of the drawing, such as slabs, either as linear or polygon themes. Polygons can further be extruded providing useful 3D displays of the trench contents. It is also possible to digitise individual layers depicted in the section in the 3D environment as 3D polygons and link these to information in the database (Fig. 8).

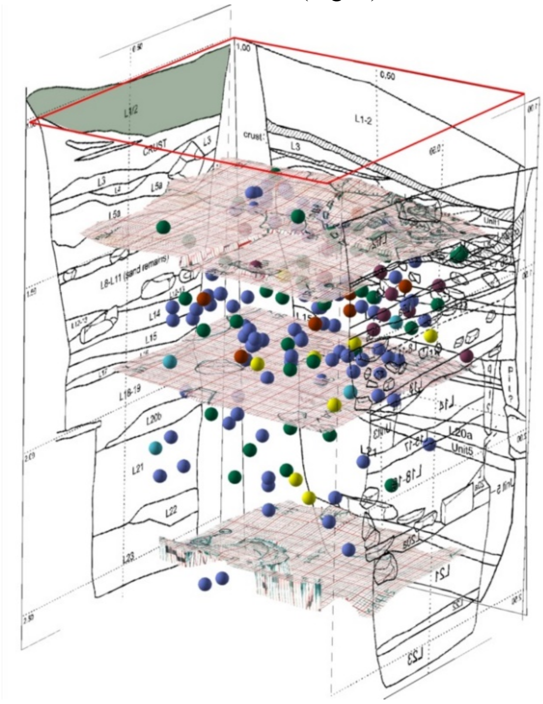

Figure 8 Modelling of sections, drawings and finds.

The process was complemented by the organisation of available information either in free-text journal entries or in spreadsheet catalogues into distinct tables within the geodatabase that can be linked to each spatial entity (e.g. excavation units linked to the content information, such as soil consistency values, counts of bulk finds etc.). In this respect, all spatial features can be combined into selective displays that visualise thematic information in space.

3. Experimenting with archive pictures

Following recent developments in computer vision based approaches for the 3D registration of archaeological features (e.g. De Reu *et al.* 2013), in the case of Ayia Triada we experimented with the available photographic archive to produce realistic photo-textured excavation surfaces. Using typical photogrammetric 3D reconstruction techniques alongside custom developed algorithms (Douskos *et al.* 2009, Stentoumis *et al.* 2013) relative and interior orientations of all available images are estimated. Images are georeferenced using Ground Control Points (GCPs) from the plan drawings. Subsequently, through dense stereo or multiple view 3D reconstruction algorithms, combined with texture mapping, the final 3D meshes are generated. In this way detailed models of high visual quality and geometric accuracy have been estimated from small groups of pictures. These models can be imported into GIS as a textured polygonal model (multipatch feature class object) and be used as-is or as a background for 3D line drawing digitisation (Fig. 9).

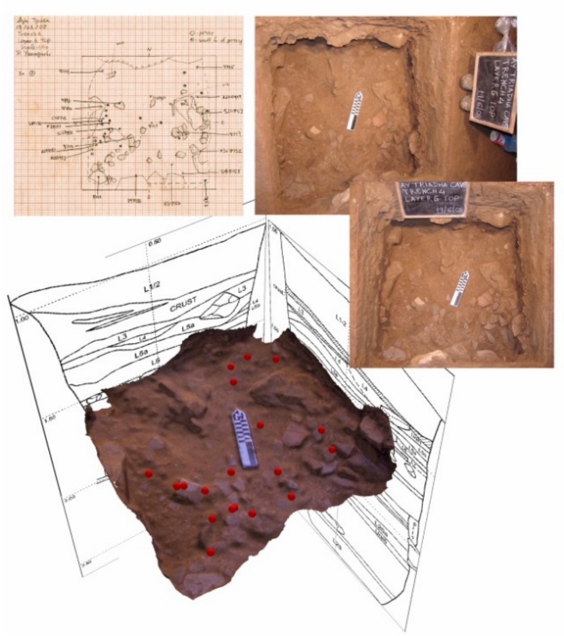

Figure 9 Surface calculation using pairs of uncalibrated photos and 3D reconstruction techniques (area 1x1 m^2.). Result shown in combination with finds as 3D points and section drawings.

The accuracy of the resulting models depends on the number and geometry of the relevant photos. In many cases, it is still impossible to generate accurate enough models, especially if images are not taken with 3D reconstruction in mind (e.g. single shots or images captured from the same position). In our tests, even when using pairs of pictures and an average of 5 well distributed control points, the overall RMS error was within a range of 1 cm (surface area 1x1 m^2). The possibility of obtaining 3D geometry from archived pictures can be used in conjunction with other excavation records resulting in more legible visual reconstructions of excavation space.

4. Data exploration in 3D

The integration of excavation data within a 3D cartographic environment primarily facilitates the visual exploration of information that was originally recorded separately. By selectively combining information from different excavation seasons or trenches, excavation questions can be investigated on a greater scale.

3D representation allows a better grasp of the spatial relationships between excavation data, by viewing them in conjunction with the drawn documentation from carefully chosen angles and focus. The representation of each theme can be limited to the objects that follow specific spatial, temporal and thematic constraints set by the users using definition queries.

The ability to combine information that was originally logged separately, frequently reveals a number of recording inconsistencies. Visualisation in 3D noticeably facilitates the indication of recording inaccuracies, such as the placement of a wall on plan or section drawings (e.g. observe wall discontinuities in Fig. 3) allowing for necessary rectifications. It also provides an assessment of the excavation process by revealing the success in detecting the limits of a deposit during excavation.

Excavation features can also be explored using the information recorded in the attribute data tables. Through the use of retinal variables (e.g. colour, size) or rendering parameters (e.g. transparency) data classification provides an effective way to get immediately an idea about data patterning. Any feature can be identified onscreen and provide access to related information, photos or graphic material.

Moreover, complex queries using thematic, temporal and spatial data attributes can be formulated resulting in the selection of the corresponding objects within the map frames (Fig. 10). Basic operations such as measuring distances or selecting objects based on 3D buffering can be performed on either single point or multipoint entities (Fig. 11). Finally, temporal change, such as the process of excavation or the succession of the deposits, can be monitored and communicated using selective displays or animations.

Conclusion

Both examples from Toumba and Ayia Triada manifest the potential of revisiting old datasets using 3D spatial technologies. The targeted use of 3D modelling procedures and GIS can contribute to the spatial augmentation of existing datasets. Their display within a 3D cartographic environment facilitates interactive approaches to data exploration allowing an improved understanding of stratigraphic relations and spatiotemporal patterning.

It must be stressed though that any attempt to enhance existing datasets involves a great deal of data mining and data manipulation, plus it is subject to the particularities of the specific excavation archive and the methods used for its compilation. In this respect, all effort going into creating 3D representations of excavation space should be justified by the intended interpretative result, rather than the visual outcome - which can range from very realistic to moderately schematic. Certainly, the application of these methodologies in further examples has the potential to extend the functionality of existing tools and create a portfolio of case studies covering a wide range of archaeological research.

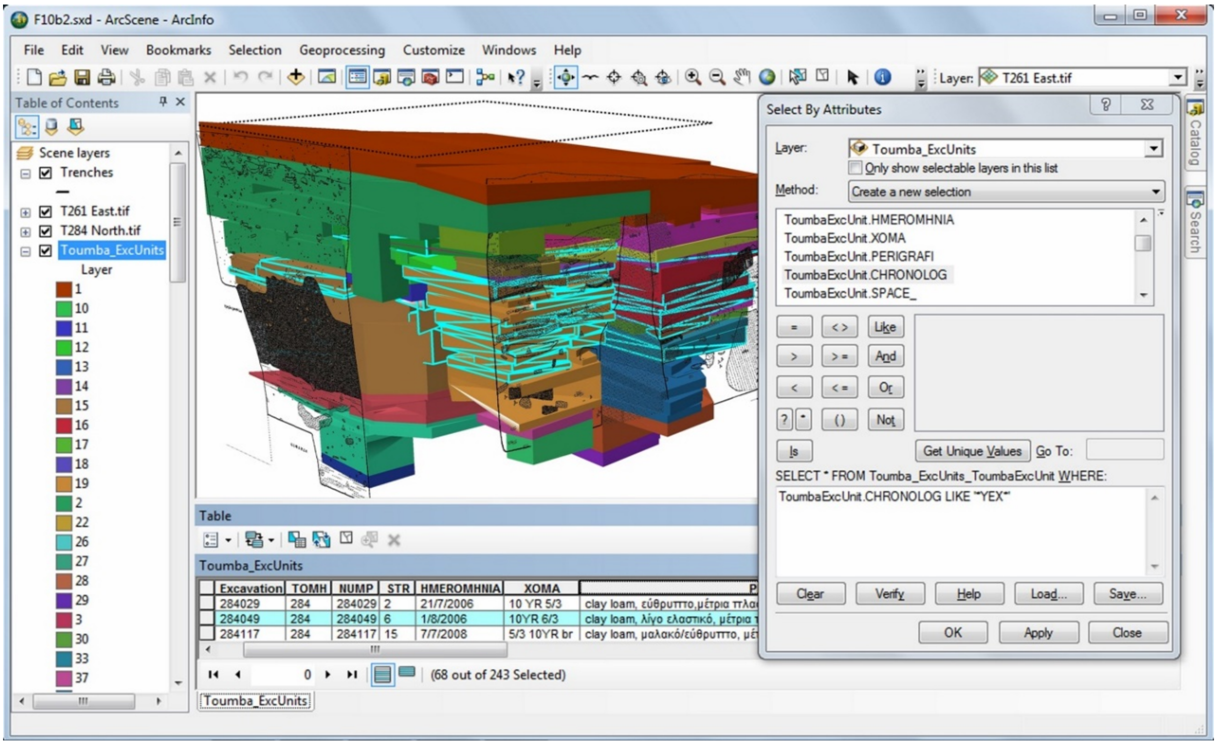

Figure 10. Thessaloniki Toumba. Classification of excavation units from Trench 284 according to stratigraphic layers and selection of those with indication of Late Bronze Age (n.b.*YEX*) pottery. Trench sections are shown in transparency.

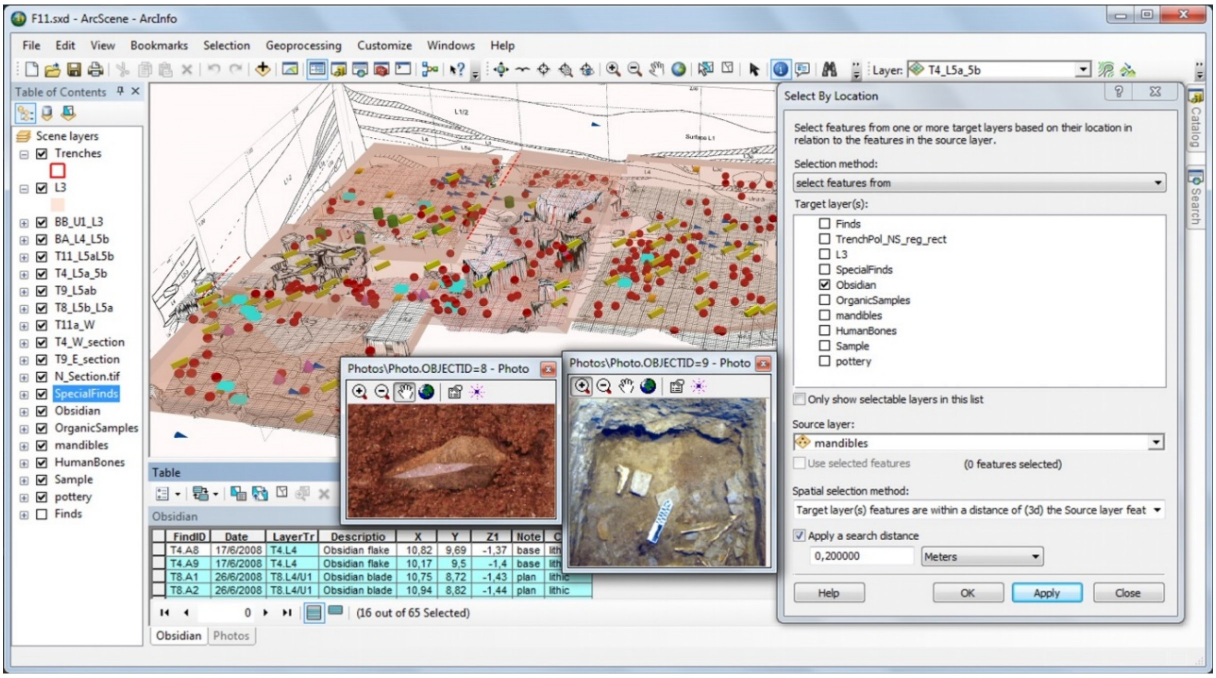

Figure 11. Ayia Triada Karystos. Selection of obsidian artefacts (blue) based on 3D distance from mandibles (orange), on-screen identification of a selected artefact and retrieval of related information and photos. Pottery sherds and bones are depicted in red and yellow respectively. Excavated layers are shown in brownish purple with transparency, section and plan drawings in greyscale.

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A REVIEW ON THE POTENTIAL USE OF CORONA IMAGES OF GREECE

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Περίληψη/ Abstract

Ένας πολύ ιδιαίτερος τύπος δορυφορικού συστήματος, που προηγείται χρονικά από αισθητήρες που χρησιμοποιούνται σήμερα, είναι ο κατασκοπευτικός δορυφόρος CORONA (1963–1972). Ο CORONA αναπτύχθηκε στο πλαίσιο του προγράμματος μυστικών υπηρεσιών των ΗΠΑ κατά τη διάρκεια του Ψυχρού Πολέμου. Προτείνεται η εκτεταμένη χρήση των δορυφορικών εικόνων CORONA για (α) τον εντοπισμό νέων αρχαιολογικών χωρών, (β) την μελέτη της μορφολογίας οικισμών και (γ) την εκτίμηση του επιπέδου φθοράς στην πολιτισμική ιδιοκτησία κυρίως λόγω της χωρικής ανάλυσης τους, της ημερομηνίας λήψης και της ευρείας γωνίας σάρωσης. Παρόλα αυτά, τα πλεονεκτήματα του συστήματος CORONA, μειώνονται λόγω των έντονων χωρικών παραμορφώσεων που είναι σύμφυτες σε μία πανοραμική σάρωση. Οι εν λόγω παραμορφώσεις μειώνουν δραστικά την χωρική ακρίβεια των δεδομένων. Γι' αυτό το λόγο μελέτες που υπάρχουν στην παρεμφερή βιβλιογραφία, είτε επικεντρώνονται στην οπτική ερμηνεία των εικόνων CORONA χωρίς την εφαρμογή γεωμετρικής διόρθωσης, ή εστιάζουν σε υποσύνολα της εικόνας όπου χρησιμοποιούνται εδαφικά σημεία ελέγχου για να διορθώσουν τις παραμορφώσεις. Στην παρούσα μελέτη αναλύονται σε βάθος τα φωτογραμμετρικά προβλήματα που συνοδεύουν μία πανοραμική σάρωση του CORONA KH4, ενώ παρουσιάζεται εν συντομία το 'CORONA Atlas' της Μέσης Ανατολής, μία επιτυχημένη προσπάθεια αξιοποίησης του συγκεκριμένου αισθητήρα. Τέλος, εξετάζεται η δυνατότητα υλοποίησης αντίστοιχου άτλαντα στην Ελλάδα, μέσω χαρακτηριστικών παραδειγμάτων.

A very special form of a satellite system pre-dates many of the sensors today. The CORONA spy-satellite system (1963 to 1972) was developed as part of the US intelligence program in the Cold War era. Due to its spatial resolution, date of images, and wide scan angle we suggest CORONA has extensive use in (i) finding new archaeological sites (ii) studying settlement morphologies (iii) assessing the level of damage on a cultural property. However, CORONA's advantage is diminished by extreme spatial distortions inherent in a panoramic scan. These distortions drastically lower the spatial accuracy of the data. Therefore, scholars either solely focus on visual interpretation of CORONA images without any geometric correction or they work on image subsets where ground control points are used to correct distortions. This study involves an in depth discussion on the photogrammetric problems, inherent to a CORONA KH4 panoramic scan. Next, we briefly introduce the 'CORONA Atlas of the Middle East' — a successful effort in widely utilizing this historic sensor. Finally, we evaluate the feasibility of a potential 'CORONA Digital Atlas of Greece' by providing unique examples.

Keywords: Satellite Remote Sensing, CORONA, Greece, Digital Atlas

Introduction

Working in favour of archaeology, there has been a significant increase in the spatial resolutions of satellite sensors. Early systems, such as Landsat Multispectral Scanner (MSS) had 60m resolution. In the next generation Thematic Mapper (TM) sensor, the resolution was improved to 30m. While providing relatively course resolution, these sensors are widely used in archaeological studies (e.g. Cox 1992, Shennan & Donoghue 1992). Another sensor series used in archaeological applications is SPOT (1, 2, 3 and 4) (Hritz 2006, Joyce *et al.* 1981). These sensors have 10m resolution in pan-chromatic band at Nadir. The next generation SPOT 5 can resolve the ground at 2.5 meters.

The trend in the increase of spatial resolutions became clearly visible with the introduction of very-high resolution commercial earth observation satellites. Global Imaging System 2000 on QuickBird can collect panchromatic data at 60–70 centimeter resolution. Another commercial satellite, Ikonos can provide 1m panchromatic data. There sensors are also of interest to researchers (e.g. Garrison *et al.* 2008, De Laet *et al.* 2007, Masini & Lasaponara 2007). The new generation WorldView-3, a commercial Earth observation satellite, can provide panchromatic data at 0.31m. Implication of this unprecedented ground resolution remains to be seen.

Despite the power of these very-high resolution commercial earth observation satellites, Key Hole (KH) cameras, mounted on CORONA satellites provide invaluable imagery due to their ability to solve the ground. Furthermore, they offer a large deal of historicity of the past landscapes.

1. A Unique High Resolution Satellite: CORONA

The CORONA spy-satellite system (1963–1972) was developed as part of the US intelligence program in the Cold War era (Day *et al.* 1999). CORONA images were obtained before the massive scale constructions, industrial agriculture, and urban expansion (Casana *et al.* 2012). The impact of such land-use land cover changes on the preservation of ancient material culture is immense, and in many cases, there is complete loss. Therefore, the value of CORONA imagery as a snapshot of the area before the drastic landscape transformation is beyond doubt. Realising this, archaeologists of the Middle East were quick to employ this invaluable data source (e.g. Kennedy 1998, Challis *et al.* 2002, Ur 2003, Casana *et al.* 2012). However, scholars of modern and ancient Greece seem to be relatively behind in adopting CORONA for their studies.

However, this system is not only used by archaeologists. Studies in glacial geology (e.g. Bolch *et al.* 2008), geology (e.g. Murphy & Burgess 2006), land use (e.g. Kostka 2002) change detection (e.g. Franklin *et al.* 2005), environmental monitoring (e.g. Hamandawana *et al.* 2005), forestry (e.g. Andersen 2006), and agriculture (e.g. Elmqvist & Khatir 2007) employ CORONA imagery with considerable success.

The large spatial coverage of a single CORONA image enables researchers to document past landscape at a wider scale. CORONA also offers high temporal resolution. Areas were visited by more than one CORONA mission at different times of year. Since the visibility of archaeological features depends on geometric, geographic and geological as well as local soil conditions, multiple images from different dates increase the detection probability of archaeological features. Another unique opportunity CORONA provides is the stereoscopic view in selected missions. It is possible to create historic elevation models and to analyse CORONA in three dimensions using stereo-pairs (Casana & Cothren 2008). Through these topographic data, researchers can study site-taphonomies and landscape processes which might have affected site preservation and their destruction.

2. Some Examples from Greece

In order to evaluate the potential use of CORONA images of Greece, we investigate four CORONA image strips (DS1110-2236DF026, 27, 28, 29) and highlight significant findings in the proceeding sections. For guidance, we employ Pleiades, a community-built gazetteer and graph of ancient places (http://pleiades.stoa.org/) and a web GIS database of Neolithic sites, located in Thessaly, Greece (http://neolithicthessaly.ims.forth.gr). In the upcoming examples, all modern imagery is courtesy of Google Earth™ mapping service.

2.a Finding New Sites

CORONA imagery can be used for finding new sites which were not previously recorded. Due to the ways in which archaeological features appear on CORONA imagery, it is possible to investigate archaeological landscape in an extensive manner and add to the cultural inventory of the area.

Located at lon: 21.893 lat: 39.480, CORONA imagery reveals a very dense architectural pattern which is also bounded by a possible city-wall. Modern imagery does not contain this information, and only a single part of the 'city-wall' is visible (Fig. 1). A similar new finding is located at lon: 22.151 lat: 39.333. A very substantial building clearly appears on CORONA imagery where individual rooms can be easily mapped — this building is not visible on modern imagery. On the other hand, modern data shows the location of a recent building which must have destroyed parts of this potential archaeological property (Fig. 2)

Two other examples (Fig. 3, 4) potentially indicate new prehistoric sites which are not available in the Neolithic Thessaly database of the Institute for Mediterranean Studies. Known examples of the mounded Neolithic settlements (magoulas) are circular in shape and at times they are obtrusive in the landscape. On the other hand, dense agricultural practices in the area have been deforming and levelling these sites. The remains of these sites are not visible on the modern satellite imagery but thankfully they appear as circular anomalies on the CORONA imagery. While in Fig. 3 there is no evidence of the past on modern imagery, Fig. 4 reveals the locations of two potential prehistoric sites albeit without revealing the sizes of these settlements.

2.b Site Damage

Industrial-scale agriculture, massive construction projects, urbanization, and alike have immense impact on archaeological sites and features. Due to its historic character, CORONA imagery provides the means for detecting damage on archaeological property which happened after 1970s. Furthermore, if there is no other historical imagery (e.g. aerial photographs) CORONA remains as the only high spatial resolution data source prior to the destruction.

We provide here a single example from the Neolithic site of Magoula Sykeonos. The comparison of modern and CORONA imagery reveals a large pool constructed at the edges of the settlement, destroying the potential extension of settlement to the southeast.

Furthermore, CORONA imagery can be used to document the extents of the settlement. Unfortunately, this is not possible via modern imagery anymore (Fig. 5).

Figure 1 Dense architectural pattern of an ancient city visible on CORONA imagery (bottom).

Figure 2 Substantial architectural features are clearly visible on CORONA imagery below.

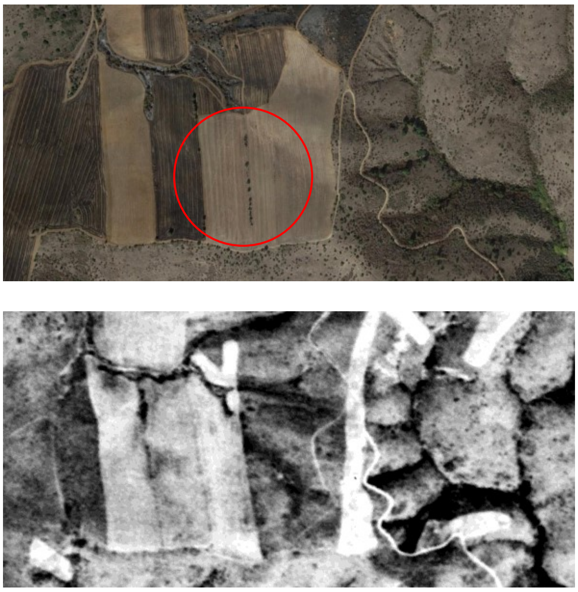

Figure 3 A possible location of a prehistoric settlement. Modern imagery has no evidence for this site, but CORONA imagery reveals a slight topographic impression of a site with a circular shape (lon: 22.165, lat: 39.513)

Figure 4 Two possible prehistoric sites are visible on both images. On the other hand, modern imagery is far from providing shape-related information (lon: 22.252, lat: 39.529).

Figure 5 A pool was constructed at the vicinity of Magoula Sykeonos, destroying parts of the site.

2.c Features Detection

Due to its high resolution, CORONA imagery can be used to detect and map archaeological features. Even though most of the modern sensors now provide data below 1 meter spatial resolution (in comparison to CORONA imagery with 1.8 meters resolution at nadir) CORONA remains preferable due to its temporal domain.

Modern imagery from Batiai (Fig. 6) clearly shows the city walls of the Hellenistic settlement even in greater detail than the corresponding CORONA image. On the other hand, the more recent image cannot reveal the full extent of the wall due to forest coverage (red circle). In contrast, one can easily document the city wall on CORONA imagery. Furthermore, CORONA imagery also reveals another section of the hill-top settlement which was also bounded by another wall (blue circle) which is invisible to the researcher when using modern data.

Another site of potential interest is Kassope which was under occupation from Archaic to the Roman periods (Fig. 7). In this case as well, modern imagery provides a very detailed picture of architectural features of the site. On the other hand, another feature (red circle) is completely missing in this imagery. Furthermore, two parallel roads (blue circle) with past origins appear as completely destroyed in the modern imagery.

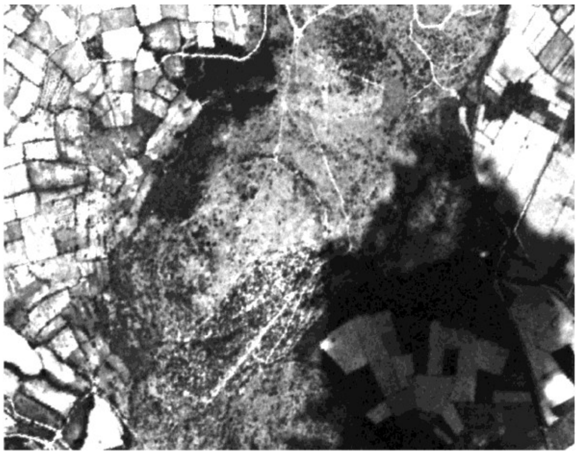

Figure 6 CORONA imagery from Batiai shows the complete layout of the city wall as well as another potential area bounded by another wall.

Similarly, at Xyniai we were able to locate an extension to the south of the city wall on CORONA imagery (Fig. 8). Even though modern satellite data provides a detailed picture of the layout of the settlement, this specific extension which is also bounded by walls is not visible (red circle).

Among these selected examples, the most significant findings come from the city of Nicopolis (Fig. 9). A quick inspection of CORONA imagery exposes numerous architectural features as well as roads of various lengths. At this point, we should note that using different CORONA imagery of the same area (coming from other missions) will only increase this inventory since visibility conditions of archaeological features also depend on ground conditions, and various CORONA missions capture this variation in great detail.

Figure 7 Elements of the ancient city of Kassope are both visible in modern and CORONA imagery.

Figure 8 At Xyniai, CORONA reveals an extension to the settlement.

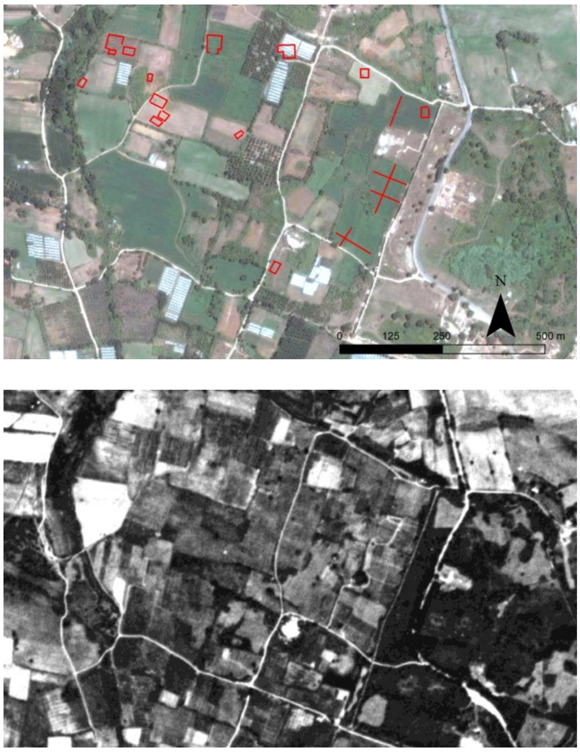

Figure 9 Urban elements of ancient Nicopolis are visible on CORONA imagery. Modern imagery provides no extra information regarding the site. Features in red are drawn on modern imagery for comparison purposes.

2.d Studying Urban Planning

CORONA imagery can also be used for investigating urban expansion and details of planning. Due to its historicity, CORONA not only shows the expansion of towns and cities, but it also provides the opportunity for studying the foundations of urban places. At Gelanthi, CORONA reveals an area of interest to the southeast of the city in which we observe the elements of an older city block (Fig. 10). It is also possible that this older block represents an archaeological settlement; yet without ground-trothing this is not possible to verify.

2.e Land Use Change

CORONA is helpful in detecting land use changes. Since the system provides high spatial resolution data, such changes are clearly visible on this historic image source. Furthermore, large spatial coverage of CORONA enables investigation over large landscapes. This makes it possible to contextualize data and to gain better information on the evolution of land use practices.

Figure 10 At Gelanthi, one can observe the initial planning stage of the town on CORONA imagery. the seeds of urban planning.

In 2014, agricultural fields located at around lon: 22.062, lat: 39.394 have northeast-southwest orientation. CORONA imagery from 1970 also suggests that orientation has been preserved since then. On the other hand, marks from earliest phases suggest a clear orientation of north-south direction (Fig. 11).

2.f Existing Site Morphologies and Boundaries

CORONA is also useful for reinvestigating existing cultural inventories. Through such investigation it is possible to detect how archaeological settlements might have been affected from damage. Or simply, one may gain extra information which is not immediately available to researchers through the study of modern imagery.

The Middle-Late Neolithic settlement Platomagoula Pyrgou Kieriou is circular in shape with a diameter of *c.* 250 meters (Fig. 12). The shape information of this previously documented site is possible only after a quick investigation of CORONA imagery. This also suggests that CORONA can be used for building an extensive morphological database of ancient settlements. In return, such database can be used to explore dimensions of socio-political and economic livelihoods of ancient people through statistical analysis of site morphology metrics and perimetrics.

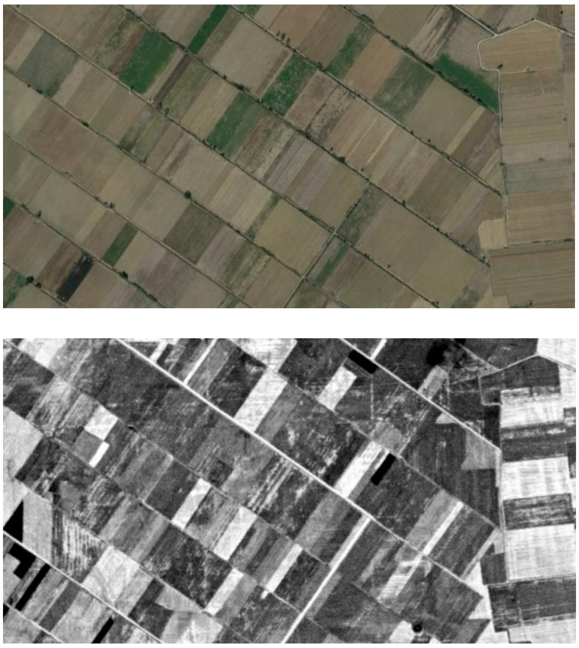

Figure 11 CORONA imagery reveals a hidden north-south orientation of agricultural fields.

Figure 12 Size and shape of the Neolithic Pyrgou Kieriou is visible on CORONA imagery.

3. CORONA Image Distortions

Within the CORONA program, the KH-4 series (also used in this study) provides the highest spatial resolution with a dual panoramic camera system. However, its advantage is diminished by extreme spatial distortions inherent in a panoramic scan. These distortions drastically lower the spatial accuracy of the data (Casana & Cothren 2008).

Therefore, scholars either solely focus on visual interpretations of CORONA images without any geometric correction (e.g. Birch-Thomsen *et al.* 2001, Maathuis & Van Genderen 2004) or they work on image subsets where ground control points are used to correct distortions (e.g. Grosse *et al.* 2005). In few cases, these ground control points are used to estimate image parameters for a photogrammetric solution (Bolch *et al.* 2008, Casana & Cothren 2008).

There is no built-in bundle adjustment for CORONA sensors. The relation between the CORONA sensor and the ground cannot be directly solved directly since many of the camera parameters as well as the payload flight characteristics during image acquisition are unknown. To overcome this problem, Sohn *et al.* (2004) proposes three methodologies. The first method involves removing distortions in panoramic photo coordinates. Regular colinearity equations commonly used for solving frame camera parameters are transformed to a cylindrical film surface conforming to the panoramic scan. The relation between image coordinates of the cylindrical film and a tangential plane are used to generate a modified set of colinearity equations. In the final equation, there are 9 unknown parameters which can be solved by 5 ground control points.

The second method involves estimating exterior orientation parameters of the camera system by time dependent variables. In this case, similar to linear array sensors, scan line maintains its relative position with respect to the central-projection. Due to fast scanning, time-dependent exterior orientation parameters are in linear form. In this case, transformed colinearity equations with 14 unknown parameters require at least 7 ground control points for the solution.

The last method is based on a replacement sensor model. In this model, the relation between image and object point coordinates are given by a polynomial function. The solution for the polynomial coefficients depends on a large number of ground control points, depending on the order of the polynomial function. Also, least squares estimation of the solution is unreliable as the number and the distribution of ground control points cannot always satisfy a direct linear transformation.

Building over Sohn's work, (Cothren *et al.* in prep) we suggest a panoramic sensor model which uses minimal number of ground control points to achieve an accurate photogrammetric solution. And recently, researchers at the University of Arkansas developed an efficient workflow for correcting CORONA images photogrammetrically. The methodology was used to build the "CORONA Atlas of the Middle East" (corona.cast.uark.edu), providing a large inventory of spatially accurate CORONA images.

4. CORONA Digital Atlas of Greece

The above methodology is replicable for the CORONA images of Greece. Having already established collaboration with the Center for Advanced Spatial Technologies at the University of Arkansas, we have recently initialized a project, called "The CORONA Digital Atlas of Greece" following the methodology below:

1. Image Acquisition and pre-processing: Approximately 150 CORONA images cover mainland Greece. The United States Geological Survey is in charge of the distribution of CORONA images. Due to its large dimensions, CORONA film negatives are scanned in four parts, and the user obtains these files separately. Following the acquisition of images, we plan to restore original images in batch-processing mode.

2. Bundle Adjustment and Orthorectification: There is no off-the-shelf bundle adjustment software for CORONA sensors. The relation between a CORONA image and the ground cannot be solved directly since many camera parameters during image acquisition are unknown. Following Cothren *et al.* (in prep), we propose to correct CORONA images in a semi-automated manner. Finally, we plan to use SRTM/ASTER digital elevation models in order further increase the spatial accuracy of resulting image products, especially in complex terrains.

3. Building an online GIS platform: Dissemination of the final images will be based on a WEB_GIS platform (ArcGIS Server) where users can view and download CORONA images. An online GIS also makes it possible to include other spatial datasets, (e.g. archaeological sites, current coastlines, modern villages and cities) so that a better research Cothren framework is provided for the user. Further capabilities of the WEB_GIS platform will be also exploited to offer end users navigation and querying options.

Conclusions

With its high resolution, early acquisition date, and low cost, CORONA is an invaluable alternative to newer satellite systems. As this study suggests, it is also capable of detecting archaeological features which are not visible on modern data. In the absence of historic aerial imagery CORONA remains the only document of past landscapes, and thus, carries significant potential.

Throughout this study, we emphasised the importance of CORONA over modern data. However, modern imagery is not less valuable than CORONA imagery; with their spatial and spectral domains most of the sensors are superior to the

CORONA system. On the other hand, the unique combination of high resolution and historicity makes CORONA a truly unique source for many regions of the world.

Despite its potential, CORONA is relatively unknown to the scholars who are working in Greece. With this study, we propose building a ‘CORONA Digital Atlas of Greece so that this data source becomes more available to researchers. We also believe introducing such an Atlas to the scientific community will open up new research arenas and will help researchers in posing new questions.

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QUANTITATIVE DATA, HYPOTHESIS TESTING, AND ARCHAEOLOGICAL NARRATIVES: WAS THERE EVER A GREEK DARK AGE?

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Περίληψη/ Abstract

Η παρούσα ανακοίνωση εξετάζει την όλο και πιο κοινή άποψη ότι οι "Σκοτεινοί Χρόνοι" της Αρχαίας Ελλάδας δεν είναι παρά ένα κατασκεύασμα των ερευνητών, εξετάζοντας εάν ο ρυθμός ανακάλυψης αρχαιολογικών χώρων της πρώιμης Εποχής του Σιδήρου έχει αυξηθεί μετά την ανακάλυψη του χώρου στο Λευκαντί περί το 1980. Παρουσιάζω μια βάση δεδομένων με σχεδόν 4.000 Μυκηναϊκούς και Πρωτογεωμετρικούς χώρους που ανακαλύφθηκαν ανάμεσα στο 1900 και το 2010. Αν χώροι της πρώιμης εποχής του Σιδήρου αγνοούνταν κατά τον πρώιμο 20ό αιώνα, αλλά αντιμετωπίζονταν με ενδιαφέρον κατά τις πιο πρόσφατές μας δεκαετίες, θα περιμέναμε ότι ο ετήσιος ρυθμός ανακάλυψης Πρωτογεωμετρικών χώρων θα αυξανόταν μετά το 1980 κατά ένα τρόπο που θα απέκλινε από τον ρυθμό ανακάλυψης Μυκηναϊκών χώρων. Ωστόσο, τα δεδομένα δείχνουν ότι οι ρυθμοί ανακάλυψης και των δύο περιόδων ομαλοποιούνται σε αναλογία περίπου 1:1 επί ολόκληρης της βάσης δεδομένων. Τα δεδομένα λοιπόν δείχνουν ότι η έλλειψη δεδομένων της πρώιμης Εποχής του Σιδήρου δεν μπορεί να εξηγηθεί ως προϊόν της άγνοιας των στοιχείων εκ μέρους των μελετητών

This paper assesses the increasingly common view that the Greek "Dark Age" is a scholarly construct by determining whether the rate of discovery of Early Iron Age sites has increased since the discovery of Lefkandi around 1980. I present a database of over 4,000 Late Bronze Age and Protogeometric sites discovered between 1900 and 2010. If Early Iron Age sites were being systematically ignored in the early 20th century, but treated fairly in the last few decades, we would expect the annual rate of Protogeometric site discovery to increase after 1980 in a way that diverges from the rate of discovery of Bronze Age sites. However, the data show that the rates of discovery for the two periods normalize very well, to roughly 1:1 over the whole data set. This data suggests that the poverty of the Early Iron Age cannot be explained as the result of scholars ignoring the evidence.
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Keywords: Big Data, Quantification, Early Iron Age Greece, Hypotheses

Introduction

In Greek Archaeology, scholars have long debated the appropriateness of the term Dark Age, once used to describe the era between the last gasp of Bronze Age civilization and the "rise of the polis" during the Geometric and Archaic periods (now known more commonly as the Early Iron Age). Our general impression, based on the archaeological evidence, is that life during this period was nastier, shorter, and more brutish than it was in the preceding and following eras. However, a series of unexpectedly spectacular discoveries at the site of Lefkandi in the 1980s led some scholars to believe that the Greek Dark Age was not actually very dark, but that we had simply misread the evidence. In this paper, I present a new quantitative assessment of this evidence, based on a comprehensive database containing all known sites from the Late Bronze Age (periods both before and after the so-called palatial collapse), and from the subsequent Protogeometric and Geometric periods. Robust quantitative analysis of this data suggests that it is not likely to be biased or systematically flawed in a way which has made the Dark Age look "darker" than it really was. The methods demonstrated in this paper make apparent the value of gathering and taking seriously cumulative "big data" when we think about and construct archaeological knowledge.

1. Theoretical Background

Archaeologists have long had a problem with data. Our problem is not that we need more data. Our field has built up vast quantities of information over the past hundred years. Rather, the problem of archaeology is that the data we have is haunted by the ghostly spectre of the data that we know we are missing. Because we know that our data is full of gaps, but cannot identify with any precision the exact nature of those gaps, we have a very hard time figuring out what, in the big picture of history, our data really means. The archaeological record, as we know it, is itself an artefact of what we, the archaeologists, have managed to recover and record, rather than a faithful representation of some ancient source population.

If we were to hold in our minds an ideal representation of all the artefacts that once remained of a given ancient society, then eliminated all the evidence that does not survive the ravages of time, the evidence that we fail to recognize because we do not have the tools to do so, and the evidence that archaeologists simply ignore or do not manage to dig up, we would get a subset of a subset of a subset of an unknowable unknown of an original body of evidence. One of the major problems of archaeological interpretation and theory has always been related to how and whether can we get a sense of what we are missing from the archaeological record, and how to integrate these supposed archaeological ghosts into the stories we tell about the past (Collins 1975, 27; Lucas 2012, 63-66). In what follows, I propose that we can find a way to understand the absences as well as the presences in archaeological data if we leverage the methods associated with analysing 'big data' to find patterns in our datasets that are invisible when they are studied in small units.

2. Case Study

The Greek Early Iron Age provides an ideal lens through which to explain what I mean when I propose that we must try harder to understand the shape of our archaeological data. It has long been clear that we as a scholarly community know of fewer archaeological sites that date to the Protogeometric period than sites that date to the Late Bronze Age or to the Geometric period. Early scholars who studied the Early Iron Age, primarily A. Snodgrass, V. Desborough, and N. Coldstream, thus proclaimed this period a Dark Age (Coldstream 1977, Desborough 1972, Snodgrass 1971). Later scholars, however, have pointed out that there are a variety of possible explanations for the lack of remains, which might suggest that the Dark Age was not so poor, but that the material record is poor for other reasons - maybe scholars have ignored it, or it is difficult to recognize, or it exists in parts of the physical environment that have not been investigated much (Foxhall 1995, 239). According to at least one prominent Early Greek archaeologist "the concept of a dark age is more of a modern scholarly construct than one based on solid archaeological evidence…in the end, the only thing 'dark' about Early Iron Age Greece is our knowledge of it." (Papadopoulos 1996, 253).

Papadopoulos (1996) and Foxhall (1995) have made important distinctions between patterns in the ancient past and patterns in the archaeological dataset. And because the archaeological dataset is the only thing we have, besides entrenched scholarly narratives, upon which to build our understanding of this entire period, 'the possibility that the data are being systematically misinterpreted in some way, or that there is some other embedded error in our approach, deserves serious consideration.' (Dickinson 2006, 94). However, I argue that it is not really enough to raise these kinds of questions about the nature of our archaeological data set, or to idly speculate on whether we have a distorted picture of the data due to some bias in archaeological practice, since this does not really move us forward very far. In order to really understand whether or not the Dark Age really is an illusion, we must seek to test hypotheses about possible causes of distortion against the archaeological data itself.

3. Method

Using data, theories about the causes of diachronic variability in the archaeological record can be tested. For instance, if Dark Age sites in Greece were being systematically ignored by archaeologists until the 1970s, but treated fairly afterwards, we would expect the annual rate of Dark Age site discovery to increase after 1970 in a way that diverges from the rate of discovery of other archaeological sites in Greece. If Dark Age settlements were missing from the archaeological record because people during this period built houses in archaeologically invisible ways, we would expect the proportion of settlement sites to burial sites from this era to be unusually low compared to the proportion of these kinds of sites from other eras in Greek history. And if Dark Age pottery were simply impossible to recognize in survey assemblages, we would expect patterns in survey discovery rates to be uniformly low across all survey zones. Arguments about the epistemological basis of an archaeological Dark Age can thus be logically tested and falsified in convincing ways, provided the existence of a comprehensive dataset containing all of the relevant archaeological sites discovered in Greece along with a number of key attributes, such as date, method, and extent of discovery and exploration.

4. Data

Using a variety of previously published resources, I generated a geodatabase including all archaeological sites discovered in Greece since 1870. I generated the database purely based on previously published excavation and survey reports, or pre-existing studies of regions or time periods that aggregated such data, with a focus on primary excavation reports. Although most Anglophone archaeologists collecting similar but smaller-scale datasets in recent years have continued to rely on outdated sources, a much more thorough and current compendium of known archaeological sites in Greece can be found in Syriopoulos 1995. This work consists of several thousand pages of rich archaeological data, organized by period and region. Syriopoulos lists every known site from Prehistoric Greece (the Neolithic through Geometric periods) up to date through 1990, along with all of the publications of material from each site, from excavation fascicules to preliminary reports in the *Archaiologikon Deltion*. My data for sites discovered before 1990 is largely culled from this resource, but it has been updated to include all available information from preliminary site reports and full publication regarding sites excavated between 1990 and 2000 as well. Other extraordinarily useful sources for up-to-date regionally specific site discovery and description include Ksifaras 2004, Giannopoulos 2008, and Farinetti 2011. In consultation, then, with a wide variety of sources, I assembled a database which I estimate includes 3,733 individual sites, or approximately 90% of all known sites in Greece with material that dates to the Bronze to Iron Age transition (Late Bronze IIIB (LBIIIB, c. 1350-1200 BCE), LBIIIC (c. 1200-1050 BCE), Protogeometric (PG, c. 1050-900 BCE), and Geometric (G, c. 900-700 BCE) periods). Some sites did not have reliable information involving their dates or circumstances of discovery or had not been adequately published, and so I omitted them when calculating the figures below. The database stores the date of discovery, the period or periods that have also been discovered at the site, the method of discovery (survey, excavation, chance finds, etc.), the type of site (settlement, artefacts, isolated tomb, cemetery), and a variety of other attributes (Table 1).

Category	IIIB	IIIC	PG	G
ID	3382	1534	847	2970
Site Name	Miraka Rema	Kaminakion	Romanos	Antissa
Chronology	IIIB;IIIC	IIIA;IIIB;IIIC	PG	PG;G
Type	Artefacts	Artefacts	Settle.	Cem.
Method	Survey	Survey	Exc.	Exc.
Discovery	1966	1982	1960	1930
Prim. Pub. Language	Greek	English	Greek	English
Source	*Deltion* 1966 Chr 171	Lasithi Survey p.61	AD 1960 Chr 200	BSA 1930-1 166-178

Table 1 Select fields within Late Bronze Age to Early Iron Age Site Database, created for assessing the validity of the notion of a Dark Age in Greece.

5. Testing Hypotheses

In what follows, I use this 'big dataset' from Early Greece to test three different hypotheses that have previously been put forward in order to "explain away" the poverty of material that we have from the Early Iron Age. In doing so, I demonstrate the general principal that by applying logical, hypothetico-deductive strands of reasoning to large quantities of archaeological information we can move forward significantly in our understanding of the patterns that we see in the ancient past, and the ultimate meaning of the undulations that exist in accepted narratives of Early Greece.

5.a Scholarly Bias

I begin by testing the notion that archaeologists have distorted the material record by ignoring PG material before interest in it increased during the last few decades. One possible source of distortion in the data could be a historical bias in the investment of archaeological resources in investigating Bronze Age and historical rather than PG sites, since the former have long been of greater interest to more archaeologists than the latter. If the rate of discovery of Early Iron Age sites changed significantly after the surge of interest that was sparked by the spectacular Lefkandi discoveries in 1980, this might suggest that there is a lot of PG material out there that may have been missed in the early parts of the century when people were not looking for it. However, if the rate of discovery of PG sites aligns closely with the rate of discovery of sites from other PH periods through time, then that should mean that the archaeological record has probably not been distorted by archaeologists' investigative priorities.

Sites known	IIIB	IIIC	PG	G
1900	58	29	16	35
1910	111	47	38	78
1920	158	64	56	107
1930	225	87	82	140
1940	312	116	134	201
1950	327	123	140	211
1960	486	191	218	328
1970	700	304	325	496
1980	845	381	381	643
1990	1011	473	477	757
2000	1229	569	575	897
2010	1331	604	619	941

Table 2 Accumulation of known sites from IIIB-G through time, raw data.

The raw numbers show that we have discovered more sites with pre and post Dark Age material than sites with Dark Age material to date (Table 2). However, we would need to interpret this distribution differently if the rate of recovery of Dark Age material appeared to be increasing over time. If the rate of Dark Age recovery spiked in the last few decades, that would suggest that the overall number of Dark Age sites could reasonably be expected to eventually catch up to Bronze Age sites, and that the Dark Age's current disadvantage could be due to historical biases in archaeological practice.

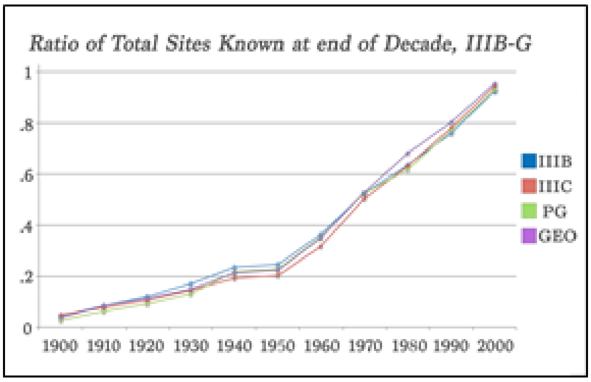

Figure 1 Normalized rates of accumulation of sites known to archaeologists, IIIB-G.

However, plotting the discovery of sites from all four periods over the course of the 20th century shows good correlation for the curves of all periods of site discovery through time. In order to make the difference in rates of site discovery more easily readable and visually obvious, I have normalized the data. To do this I divided the number of sites of each period discovered in each decade by the total number of sites eventually known, thus eliminating distortion in the visualized data based on quantitative differences in the overall totals of the data categories. The graph of normalized data thus shows the decade-by-decade pace of IIIB, IIIC, PG, and G site discovery through time - that is to say, the pace for each period to today's known total number of sites (1). Once again, there is excellent correlation for all four curves through time, with only slight diachronic variation (Fig. 1). Thus, the data suggest that, from a synoptic view, the difference between the amount of known Mycenaean and Geometric and known Dark Age material culture is not the result of biases in archaeological practice in the early history of exploration in Greece.

5.b Flimsy Settlements

Second, I test whether we do not have many Early Iron Age sites because the scrappy remains of PG settlements do not tend to survive to be discovered. Regardless of whether archaeologists have always paid close attention to Dark Age material, there could be some other reason that they do not find it, even when they are looking for it. One suggestion that has been made is that we do not have many Dark Age sites because the scrappy remains of the Dark Age do not survive well within settlement sites. If this were the case, we would expect tombs to dominate the archaeological record for Dark Age Greece. That is to say, if settlements from the Dark Age do not survive well, or if most Dark Age people were transhumant pastoralists who left little in the way of settlement remains behind, we would end up knowing most about the period from cemeteries, suggesting that we are missing huge chunks of settlement material.

In order to assess whether or not this is true, I have broken down the database of sites according to my categories of 'Period' (IIIB, IIIC, PG, or G) and Type (Cemetery, Settlement, Settlement/Cemetery together, Artefacts). According to this distribution, the proportion of sites where archaeologists have found stratified architectural remains is slightly higher for IIIB and IIIC sites than it is for Early Iron Age sites. Likewise, the percentage of cemeteries known from the Dark Age is, as a total percentage of the data, high relative to the percentages from the IIIB, IIIC, and G periods (**Fig. 2**). While these differences do confirm the notion, long-recognized, that archaeologists find more PG cemeteries than they do PG settlements, the differences are not huge.

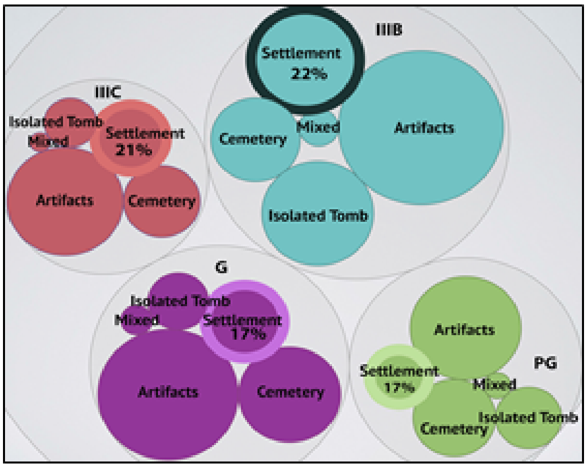

Figure 2 Comparison of the overall percentage of settlement sites from the IIIB, IIIC, PG, and G periods.

Based on the data, it does not seem very likely that the difference of a few percentage points in datasets of this relatively small size are large enough to account for the overall nearly 3:1 ratio of Bronze Age settlement sites to PG settlement sites observed in the total dataset. In general, the remarkable similarity of site-type distribution between all four of these periods strongly suggests that we have a comparable, if not totally equivalent, knowledge base for each.

If these settlements exist, why do we still have the pervasive sense that the Early Iron Age record is so impoverished in settlement evidence? One possible explanation for the dissonance is suggested in the data - an unusually high percentage of Dark Age settlement deposits (62% for PG vs. 49% for IIIB) consist of modest structures, found by the Ephorate and published in Greek. It may, then, simply be the case that the Anglo-American archaeological community, may not be aware of their existence since they do not ever filter into our normal spheres of knowledge.

5.c Poor Visibility in Surveys

Finally, one other possible explanation that has been put forward for the fact that we do not know of many sites dating to the Early Iron Age is that it is the result of the way that archaeologists go about their work, focusing on concentrated settlements rather than searching for small-scale dwellings scattered throughout an agricultural landscape. If this were true, we might expect Early Iron Age sites to score well in archaeological surveys, in which archaeologists look for cultural material that is spread around in the landscape.

This does not appear to be the case. The ratio of IIIB:PG sites found by surveys is more than 3:1, higher than the overall ratio of IIIB-PG sites of about 2:1. In addition, the percentage of all known PG sites known from surface finds in the countryside is not inordinately high (Fig. 3). At first glance, then, it does not appear that we are missing a great deal of Early Iron Age material that is spread around in the countryside.

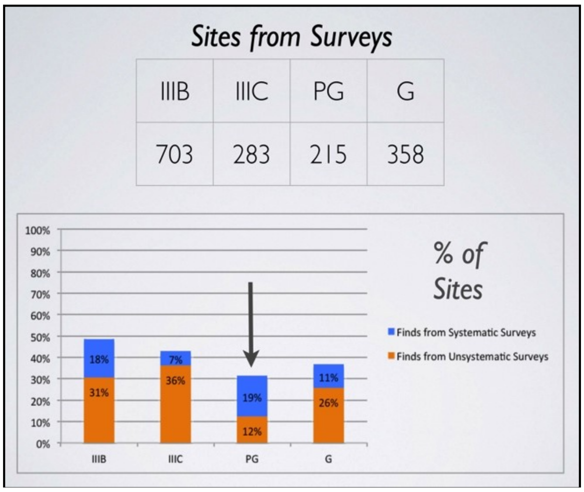

Figure 3 Distribution of survey sites from IIIB, IIIC, and PG in the total dataset (blue: finds from systematic surveys, yellow: finds from unsystematic surveys).

But, once again, we need to think again about the meaning of this information carefully before drawing definitive conclusions. It has long been recognized that there are differences in the durability and distinctiveness of pottery from different periods, and that artefacts from some periods may not score well in surveys because they are difficult to recognize or because they are too easily destructible to survive in surface deposits. If Dark Age material were difficult to recognize in survey, however, we would expect to find little to no Dark Age material in any surveys anywhere. But, while PG surface remains are not inordinately abundant, they are also not particularly sparse. Of all known PG sites, 31% come from the identification of artefacts in surveys. However, the ratio of IIIB:PG sites found by surveys is more than 3:1, higher than the overall ratio of IIIB:PG sites of about 2:1. In addition, the percentage of all known PG sites known from surface finds in the countryside is not inordinately high.
In addition, the appearance of Dark Age artefacts appears to vary significantly by region. Dark Age survey material has appeared in some regions, notably in the site registers from the Vrokastro, Almiros plain, and Methana surveys, among others, suggesting that Early Iron Age material is recognizable in surveys where it does, in fact, exist. The kind of variation that we see in the number and proportions of Dark Age material identified in survey data strongly suggests that the methods archaeologists have developed in order to identify surface remains *are* sensitive enough to pick up variation in assemblages of Dark Age material, and are thus not missing huge amounts of that material in systematic ways.

Conclusion

What all of this data shows most clearly is that there is no better explanation in the data for the scarcity of Dark Age material than that it is simply scarce. There does not seem to be a systematic bias in the archaeological record making this period look darker than it is. It is a satisfying conclusion, which allows us to go from a situation in which we think we have less material, but can't distinguish between the causes of material impoverishment (e.g. whether it is felicitous and based upon non-ancient causes or whether it actually reflects past poverty). But, more broadly, this case study makes clear a method by which the fragmentary historically contingent nature of the archaeological record can be remedied, at least somewhat and at least in some cases, by a "big data" approach to the entire archaeological record. By systematically examining the possible causes for variation in the nature of archaeological datasets through time, we can at least begin to reconstruct patterns of rise and fall in the past with better accuracy and confidence, and be in a better position to reach robust conclusions about the broad strokes of the story of the human past.

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SACRED TOPOGRAPHY IN IRON AGE CYPRUS: THE CASE OF VAVLA-KAPSALAES

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Περίληψη/ Abstract

Η παρούσα ανακοίνωση επικεντρώνεται στην άμεση σχέση των Κυπριακών ιερών με τις ενίοτε εδαφικές διεκδικήσεις των πολιτειών της Εποχής του Σιδήρου. Στηριζόμενοι σε παρόμοιες θεωρητικές και μεθοδολογικές εφαρμογές για την αρχαιολογία του τοπίου που έγιναν σε άλλες περιοχές της Μεσογείου, επιχειρούμε τη διερεύνηση της ιεραρχικής διάταξης των Κυπριακών ιερών. Η ιεράρχηση των θέσεων αυτών στο ευρύτερο περιβάλλον εκφράζει άμεσα την κοινωνική τάξη πραγμάτων και συνδέεται με τις σφαίρες επιρροής των διαφόρων Κυπριακών πόλεων-βασιλείων. Το ιερό στη θέση Βάβλα-Καψάλες χρησιμοποιείται ως πιλοτική έρευνα για να εξεταστούν διάφορες υποθέσεις που προβλήθηκαν από τους σύγχρονους ερευνητές σχετικά με τη χρήση των Κυπριακών περιφερειακών ιερών και τη διαμόρφωση διαφόρων πολιτικών και πολιτισμικών ταυτοτήτων. Ένας συνδυασμός αρχαιολογικών και γεωγραφικών δεδομένων θα χρησιμοποιηθούν προκειμένου να εξετάσουμε το ιερό αυτό στο ευρύτερο πολιτικό, οικονομικό, πολιτιστικό και συμβολικό του πλαίσιο.

In this paper we elaborate on the relationship between sanctuaries and the territorial claims of the Iron Age polities of Cyprus. Drawing on ideas from theoretical and methodological studies on landscape archaeology and their relevant applications in other Mediterranean histories, we explore how spatial order i.e., the hierarchical arrangement of sites, as observed in sacred landscapes, articulates social order and is linked with shifting relations of power and cultural influence in an ancient Cypriot context. The sanctuary site of Vavla-Kapsalaes is the case-study we employ to test various hypotheses regarding the relation between the extra-urban sacred space and the formation of various political and cultural identities in Iron Age Cyprus. Both archaeological and geographic data are implemented with GIS analyses in order to contextualise this sanctuary within its broader political, economic, cultural and symbolic landscapes.

Keywords: Cyprus, Iron Age sanctuaries, landscape archaeology, GIS

Introduction

In this article we present some preliminary results from our on-going research on the application of Geographic Information Systems (GIS) in the study of Iron Age Cypriot sacred landscapes. The present case study focuses on the sanctuary site of Vavla-Kapsalaes, and the questions we address are as follows:

1. What are the reasons behind the foundation of the sanctuary in the Cypro-Archaic period? Based on the currently available archaeological evidence, can we identify a relation between the establishment of the sanctuary and the consolidation of the power of the city-kingdoms during this period?

2. Does the combination of archaeological indicators and GIS analyses suggest that the sanctuary possessed an important hierarchical position in the economic life of a specific political territory? Does the topographical setting of the sanctuary relate to industrial (copper mining) or agricultural production?

3. Can GIS analyses complement other archaeological evidence which suggests that the sanctuary belonged to the territory of the Amathousian city-kingdom?

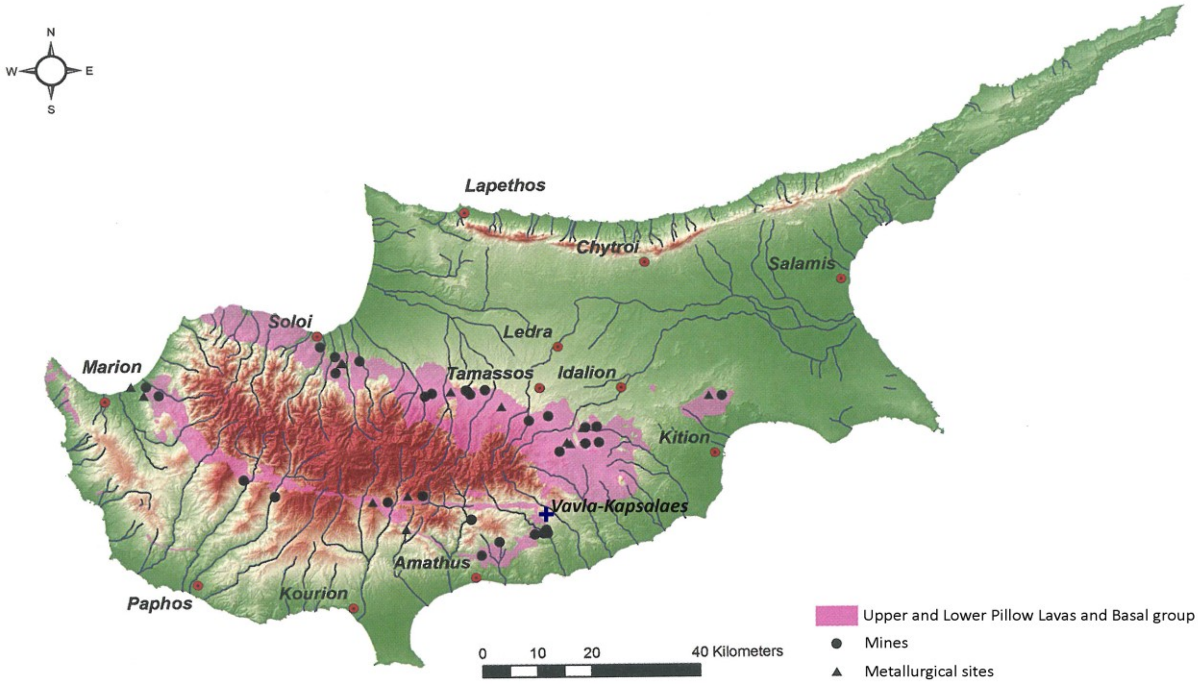

Figure 1 Map of Cyprus showing Vavla-Kapsalaes, the copper-rich Pillow Lava formation, the Iron Age Cypriot polities, and the location of mines and metallurgical sites dating to the Iron Age (after Kassianidou 2013, 51, fig. 1).

1. Cypriot Sacred Landscapes: Theoretical Framework

The Iron Age polities of the island represent the climax of an indigenous political institution, which operated with success to the end of the fourth century BCE when it was terminated by an exogenous intervention (Iacovou 2008, 2013). As Iacovou (2012) argued, the primary factor that rendered the island's economic and political unification unnecessary is the geographical distribution of copper resources all around the foothills of the Troodos mountain range (Fig. 1). It is suggested that the economic model, which shaped the political geography of Cyprus was dependent on a minimum spatial requirement: control of a unified territory that could procure copper, produce staples and had access to a gateway.

Recent research has established beyond question the role of extra-urban sanctuaries in the political establishment of the city-kingdoms of the Cypro-Archaic (*c.* 750–480 BCE) and Cypro-Classical (*c.* 480–310 BCE) periods (for further detailed discussion see Fourrier 2007, Papantoniou 2012a, 73–162, 2012b, 2013). Some sanctuary sites can be identified in the countryside, mainly towards the end of the Cypro-Geometric period (*c.* 1050-750 BCE). The multiplication of the extra-urban sanctuaries in the opening phase of the Cypro-Archaic period represents the climax of a process that could be explained within the framework of the consolidation of the political power of the different city-kingdoms (Fig. 2).

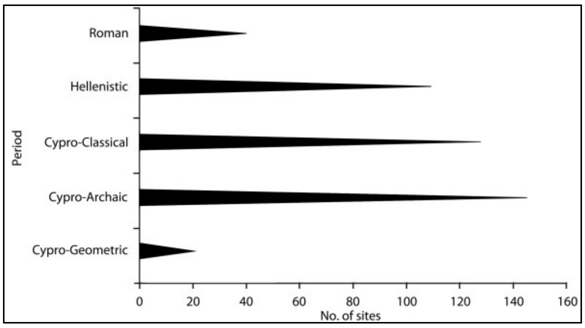

Figure 2 Density of sanctuary sites from the Cypro-Geometric to the Roman period (Papantoniou 2013, 37, fig. 5).

It has been difficult, based on past research, to discuss further any patterns in associations of Iron Age sanctuaries with cities, settlements and routes. In analogy with projects undertaken elsewhere in the Mediterranean (and usually in relation to other time-periods) where GIS methods have been employed to illuminate the sacred landscapes (e.g. Soetens *et al.* 2001, 2002, Farinetti 2011), a GIS analysis of the distribution of Cypriot sanctuaries, both across the island and on a regional level, can reveal possible relations among extra-urban sanctuaries, socio-political boundaries and networks, as well as communication and trade-routes between city-kingdoms, or among urban centres, second-rank towns and rural settlements. We will employ these geographical analyses to our regional case-study: the sanctuary site of Vavla-Kapsalaes.

2. The case of Vavla-Kapsalaes

The identification of the Vavla-Kapsalaes sanctuary was an accidental event but was followed by extensive surface survey. It is situated on the foothills of the eastern edge of the Troodos Mountains, at 493 m. above sea level. It lies on the top of a spine-like ridge, between the watersheds of the Vasilikos and the Agiou Mina Rivers, and commands an outstanding view over both river valleys (Morden & Todd 1994, Todd 2013).

The study of the locations of all the definite and possible Cypriot sanctuaries from the Cypro-Archaic to the Roman period (Papantoniou 2013), allows us to suggest that the sanctuary site at Vavla-Kapsalaes occupied a significant position in the landscape of the South-East coast of the island. It is one of the very few securely identified sanctuary sites that stand apart from groups of sanctuaries, which create rings or zones around city-kingdoms, as in the case Amathous, Idalion, Tamassos and Kition. Apparently, we are dealing with a 'frontier' sanctuary located within the zone of interest of various city-kingdoms. As will be shown below, a geographical analysis of the surrounding landscape, in combination with the archaeological material recovered from the sanctuary site (Fourrier 2007, 49, 64, fig 1, Ulbrich 2008, 281–282) suggest that the 'frontier' cult site of Vavla-Kapsalaes belonged to the territory of the Amathousian city-kingdom.

3. Datasets and Geographic Information Systems Analysis

For the purposes of this research we have collected the evidence at three different levels: 1. Material deriving from the sanctuary site of Vavla-Kapsalaes *per se*; 2. Archaeological data related to the surrounding archaeolandscape of the sanctuary, i.e. evidence of other sanctuary sites, and evidence of settlement and cemetery activity; 3. Digital data for the implementation of GIS analyses.

In our analyses we included Amathous, Idalion, Tamassos and Kition, the four urban centres around the Vavla sanctuary site, which provide some evidence for their existence as independent polities at least at some stage of the Cypro-Archaic and/or the Cypro-Classical periods (for further discussion see Iacovou 2013, 33–34).

For the purposes of this paper, the digital (both raster and vector) data used for the GIS analyses have been retrieved from the Eratosthenis Database, and were collected and created by the Department of Geological Survey and the Department of Land and Surveys of the Republic of Cyprus. The digital data used include: 1) the Digital Elevation Map (DEM) of 25m grid spacing; 2) the geological map, derived from digitisation of map in scale 1: 250000; 3) the rivers map, derived from digitisation of map in scale 1: 250000.

The accuracy of the DEM is essential for the generation of the spatial analyses (Harris 2000, 121, Conolly & Lake 2006, 101–102). The digital data described above were used in the highest resolution available. For the purposes of the current article no Global Positioning System (GPS) measurements were taken. Different approaches in the digitisation process were implemented. The position of the urban centres was retrieved from a previous publication (Papantoniou 2013). The coordinates of the sanctuary at the locality Vavla-Kapsalaes was retrieved by the online pilot application of the Department of Land and Surveys 'Navigate to a Parcel' (http://parcel.dls.moi.gov.cy/search/ParcelSearchEN.aspx). Where possible, the sanctuary sites falling within the area of interest were digitised from published maps. The exact location of some sanctuaries was not retrievable due to the nature of publication or preservation of the sites. In these instances, the sanctuaries were approximately placed.

The GIS analyses conducted on the site of Vavla-Kapsalaes and its surrounding environmental and archaeological landscape can clarify the function of the sanctuary within its contemporary political, economic and cultural landscape. For the purposes of this paper we integrated two GIS techniques, Viewshed (VSA) and Cost-Surface Analyses (CSA). The GIS analyses were conducted with an integration of commercial and Free and Open Source GIS software: ArcGIS and GRASS GIS. For the purposes of the CSA, GRASS-GIS r.walk module, an anisotropic cost surface algorithm, was implemented (Fontenari *et al.* 2005, http://grass.osgeo.org/grass64/manuals/r.walk.html). The r.walk module was employed using default slope parameters and knight's case search (Bevan 2010, 46). VSA was conducted in ArcGIS, using the viewshed tool, with default parameters (http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=Performing_a_viewshed_analysis).

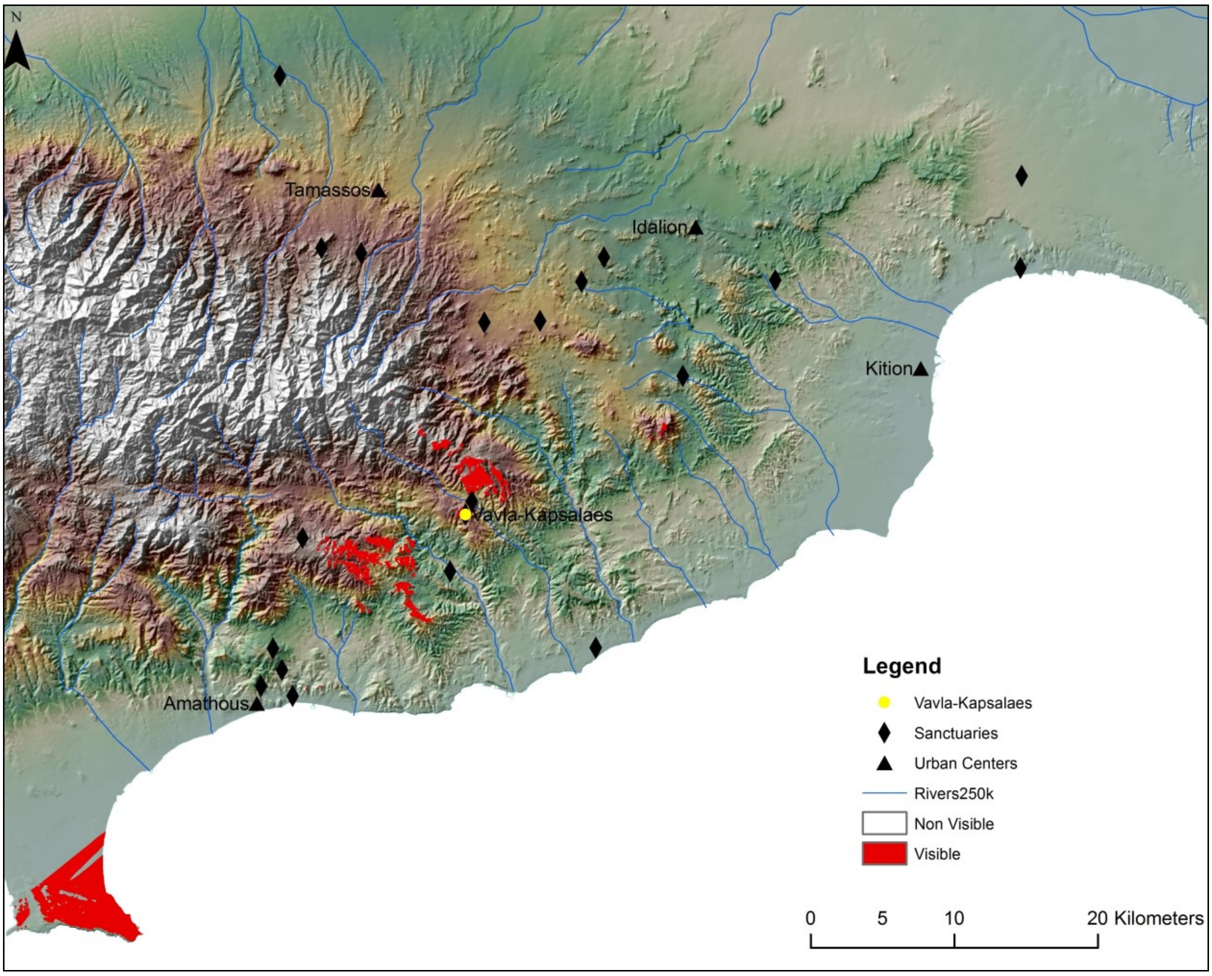

Figure 3 VSA results from Vavla-Kapsales (digital data courtesy of the Geological Survey Department, Republic of Cyprus).

4. Results

VSA analysis confirms that the Akrotiri peninsula and Cape Gata are visible from Vavla (Fig. 3). The visibility horizon from the site, places the sanctuary primarily within the Amathous 'sphere of interest'. With a probable exception, there is no visibility between Vavla-Kapsalaes and any other securely identified sanctuary in the broader region.

Future analyses on the inter-visibility between the various sanctuary sites and primary centres might provide further conclusions. What is of major importance is the fact that towards the southwest the sanctuary has great visibility of the pillow lavas and copper resources. In the future we aim to investigate further the visible access from the sanctuary to various potential agricultural soils.

The results of the CSA also strengthen the relation of the sanctuary with Amathous (Fig. 4). While one would need about 5 hours walking to reach Amathous, one would need more than 6 to 7 hours to reach any other capital centre of a known Cypro-Archaic or Cypro-Classical urban centre in the broader region.

Palaeoenvironment and palaeovegetation are issues that should be further taken into consideration when employing GIS analyses, since are factors that affect VSA and CSA (Wheatley & Gillings 2000, 5, Conolly & Lake 2006, 230–231). We are aware that the reality of the palaeoenvironment and palaeovegetation might have been different, but based on the existing stage of research, we have to base our arguments on the existing data. The published information regarding the vegetation of the area, comes from Christodoulou's land use map, generated from aerial photographs taken in 1949 (Christodoulou 1959). This map illustrates that the area of interest was covered with tree and other perennial crops, irrigated crop land, unirrigated crop land and unimproved grazing land (Christodoulou 1959, 106–108). Additionally, Christodoulou (1959, 111) describes our area of interest as sparsely wooded. An additional source of modern land coverage on Cyprus is provided by the Land Use Corine 2006 map (http://www.eea.europa.eu/data-and-maps/data/clc-2006 -vector-data-version).

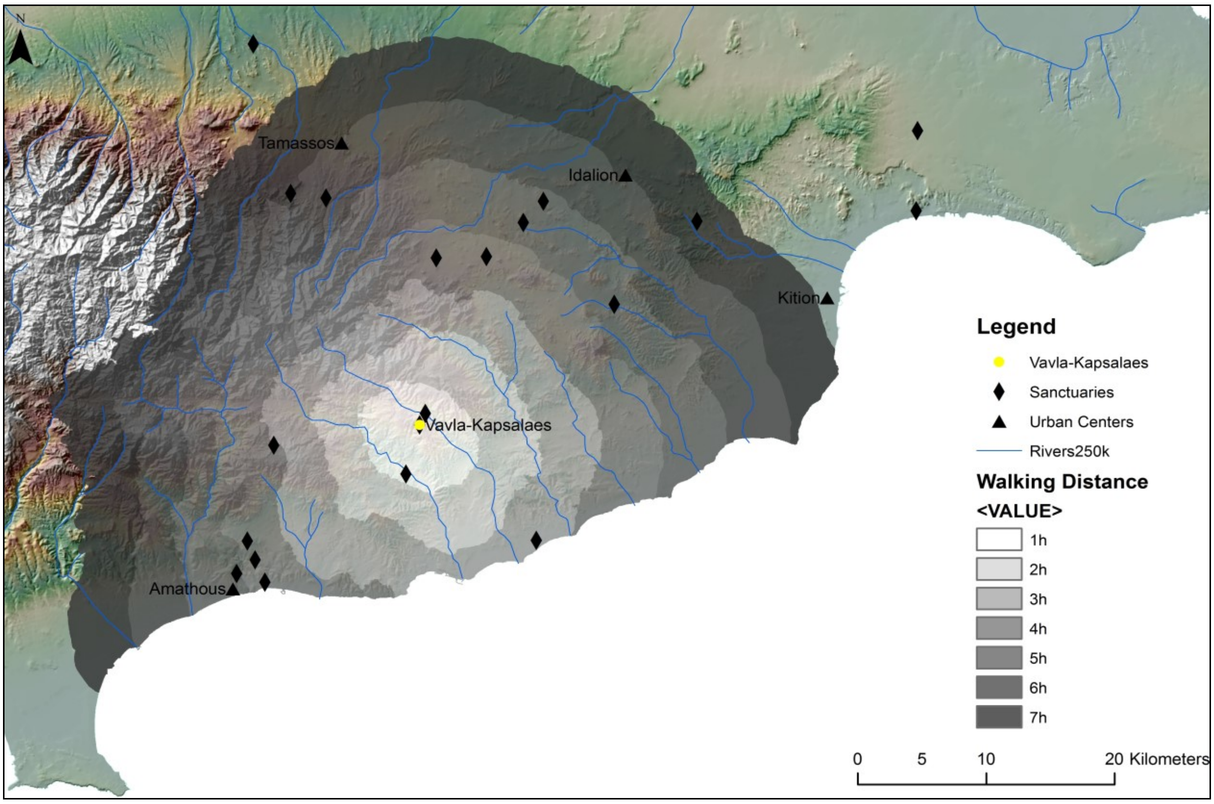

Figure 4 CSA results from Vavla-Kapsalaes towards the urban centres (digital data courtesy of the Geological Survey Department, Republic of Cyprus).

The map describes the area surrounding Vavla as agricultural and forest/semi-natural area. The contemporary vegetation in the area is rather low, and no massif woodland is present that could affect the results of the GIS analyses. Further survey could provide insights to the palaeoenvironment and palaeovegetation enabling us to understand in detail the possible environmental boundaries (e.g. rivers, and woodland), that could have affected the vision and transportation in the area.

As we develop our research on the topic multivariate statistical analysis may be employed. A future step would be the conduct of Principal Components Analysis and Chi-squared test on both the results of CSA and VSA, providing the means to test their validity.

Conclusions

This preliminary research claims that the establishment of the sanctuary cannot be seen in isolation of the processes that led to the consolidation (and manifestation) of the power of the Cypro-Archaic kingdoms. The GIS analyses complement archaeological evidence, which suggest that the sanctuary site belonged to the territory of Amathous. Following previous discussion on the subject (Papantoniou 2013), the sanctuary should be seen as a 'frontier sanctuary', which could have stood between the city-kingdom of Amathous and its neighbouring polities. The sanctuary had an important hierarchical position in the economic life of the area: its topographical setting relates to the copper mines and the surrounding areas of agricultural production.

In conclusion, we feel that there is valuable scope for GIS to expand our understanding for already established knowledge on Cypriot Iron Age sacred topography. Further GIS and multivariate statistical analysis will refine the model and determine the environmental and topographical characteristics of the extra-urban Cypriot sanctuary on the scale of its surrounding and contemporary archaeolandscape. The refinement of the GIS model in the future will allow us to define even better the choice of location, the function and the meaning of Cypriot extra-urban sanctuaries.

Acknowledgments

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INVESTIGATION OF ARCHAEOLOGICAL MOUNDS WITH 3D RESISTIVITY TOMOGRAPHY: THE CASE OF TOLTEC MOUND B, ARKANSAS, USA

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Περίληψη/ Abstract

Η εργασία αυτή περιγράφει τα αποτελέσματα της εφαρμογής της τρισδιάστατης ηλεκτρικής τομογραφίας για την χαρτογράφηση της στρωματογραφίας του τύμβου Β στο Αρχαιολογικό Πάρκο Τολτεκ των Ηνωμένων Πολιτειών. Για τον σκοπό αυτό πραγματοποιήθηκαν παράλληλες ηλεκτρικές τομογραφίες καλύπτοντας μία έκταση 9.600 τετραγωνικών μέτρων. Το ψηφιακό μοντέλο εδάφους του τύμβου κατασκευάστηκε με την χρήση ενός ρομποτικού γεωδαιτικού σταθμού. Οι κατακόρυφες και οριζόντιες τομές του υπεδάφους του τύμβου ανακατασκευάστηκαν με την επεξεργασία των δεδομένων με δισδιάστατους και τρισδιάστατους αλγορίθμους αντιστροφής. Τα αποτελέσματα της γεωφυσικής διασκόπησης βοήθησαν στην κατανόηση των διαφορετικών σταδίων κατασκευής του τύμβου μέσω της μελέτης της αντίστοιχης στρωματογραφίας.

This work describes the results of a three-dimensional (3D) electrical resistivity tomography (ERT) survey in order to map the subsurface resistivity properties below Mound B at Toltec Archaeological State Park in Arkansas, USA. A dense network of parallel pole-dipole ERT lines covered an area of 9,600 square meters. A robotic total station was used to compile a detailed digital elevation model of the mound. The data were approached with both 2D and 3D resistivity inversion algorithms in order to create vertical sections and horizontal slices of the subsurface. The ERT survey managed to map the stratigraphy providing a detailed model of the mound's filling material as well as information on its historical habitation.

Keywords: Mound, geophysical methods, 3D ERT, Toltec, USA

Introduction

Barrows, mounds, tumuli, kurgans, and tells (Ashbee 1984, Andronicos 2004, Goldberg & Macphail, 2006) are artificially erected hills with small or large dimensions that have a worldwide distribution and cover a wide time spectrum. At the same time the systematic archaeological study of these monuments offers opportunities to reconstruct habitation models regarding the life and customs during their building period. However their research by means of traditional archaeological tools (e.g. excavation) is time-consuming, costly and at the same time it affects the monument itself as well as the surrounding landscape.

As a response to the above mentioned challenges, the application of geophysical research methods (e.g. seismic refraction, seismic tomography, ground-penetrating radar, electromagnetic methods, etc) applied in archaeology can provide the necessary tools for effective and non-destructive characterizations of these structures (Tsokas *et al.* 1995, Persson & Olofsson 2004, Forte & Pipan 2008).

Geophysical investigations of archaeological mounds seek to answer specific archaeological and anthropological questions (Bigman & Lanzarone 2014) by reconstructing the cultural landscape that systematic excavation would normally need decades of tedious work to reveal. The collection of spatial geophysical data can enlighten, support or correct past archaeological hypotheses and plans or fill the gaps in the free space between the mounds (Burk, 2014). At the same time, enclosures, pits, circular ditches, middens and embankments appear with distinct signatures in geophysical readings thus making them as ideal targets for different geophysical investigations (Henry *et al.* 2014).

However, all researchers acknowledge that the geophysical investigation of such monuments is a particularly difficult geophysical problem, due to the complex subsurface resistivity distribution, the size of the buried targets and the uneven topographical terrain, thus bringing all geophysical techniques to their limits. As a result, most of the known geophysical approaches involve either qualitative interpretations or only two-dimensional approaches.

Recent developments in the field of geophysical electrical resistivity tomographic (ERT) techniques involve fully three-dimensional (3D) imaging techniques which can readily cope with complex topography (Yi *et al.* 2001, Günther *et al.* 2006). The application of such advanced techniques in archaeological mound investigation is very limited (Papadopoulos *et al.* 2010, Tsourlos *et al.* 2012, Kassabaum *et al.* 2014) although it is clear that a fully 3D tomographic approach in mound investigation is particularly useful since vertical sections in different directions and horizontal depth slices can be efficiently extracted, revealing information for different construction phases, the interior stratigraphy and architectural relics hidden into the mound.

Figure 1 View of Mound B at Toltec Archaeological Park from the south. The flags denote the position of the electrodes used to collect the ERT data.

1. Area of Investigation

The 3D ERT method was applied to Mound B (Fig. 1) at Toltec Archaeological State Park. The park is located on an alluvial floodplain of the Arkansas River in the central-east side of the state of Arkansas (USA). The modern name for the stream near Toltec Mounds is Plum Bayou and is used by the archaeological community to describe the culture of the people that built Toltec Mounds. The Toltec site is partially enclosed by an earthen embankment with an exterior ditch. Toltec is considered the largest Plum Bayou mound center of the Terminal Woodland period (700–1000 A.D.). It exhibits a formal plan with regular plazas and at least 18 mounds. The majority of them are not visible today due to the extensive agricultural activities that took place since the 1850s.

People at Toltec Mounds depended on a variety of wild and cultivated plants that were gathered from natural sources or cultivated in gardens and fields. At the same time deer, turkey and raccoon supplied almost 85% of their diet in meat. Archaeological investigations at Toltec Mounds were initiated in 1976 and are still active today. In general Toltec Mounds are considered the most significant place for Plum Bayou culture from A.D. 700 to 1050 (Rolingson 2012).

2. Field Geophysical Investigations at Toltec

The resistivity tomography survey of mounds requires a detailed topographic plan and digital elevation model of the investigated site in order to correct the apparent resistivity data for the topography effect. A robotic total station was utilized to set up the geophysical grid and record the elevations of different points along the mound by capturing more than 4,630 topography data points. The horizontal resolution of the data was 2 m by 2 m within the eastern and western part of the Mound and a denser sampling rate was chosen for the middle part of the Mound (~2 m by 1m). Afterwards a kriging algorithm was employed to compile the digital elevation of the Mound (Fig. 2).

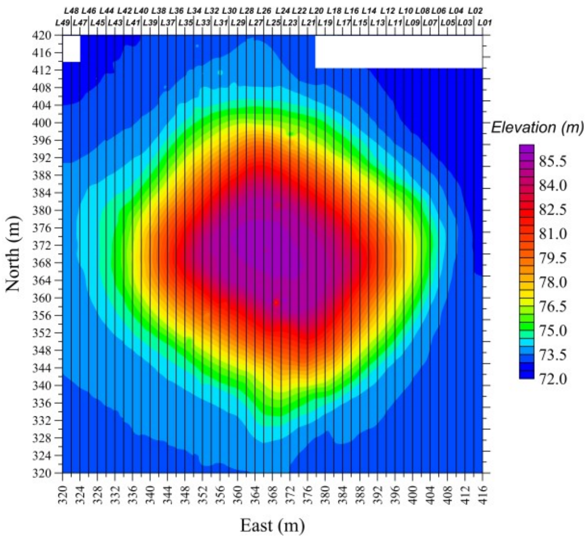

Figure 2 Digital elevation model of Mound B. The mound has a rounded rectangular shape. Its maximum height is 13.3 m. The ERT profiles (solid lines) were oriented along the South-North direction. The field coding of the ERT lines is shown on the upper axis of this figure.

A multichannel resistivity instrument was used to collect the resistivity tomography data employing the pole-dipole electrode configuration. The data were collected along south-north individual transects (Fig. 2). The profiles were parallel to each other with an inter-line spacing of 2 meters. All 49 ERT lines started from the same coordinate to the south and extended to north with length between 94 to 100 meters measuring along the ground topography. Similar field strategy and protocols were utilized to collect the data. The unit electrode distance along the lines was two meters (a=2) and the N separation (ratio of the distance between A and M electrodes to the M-N dipole length) ranged from 1 to 10. In order to increase the investigation depth and the recorded signal, additional data with unit electrode spacing “2a” with N=1–9 and “3a” with N=3–9 were also measured. The 2,430 metal stakes (electrodes) were placed on the earth using tapes by following in each case the topography of the mound (Fig. 1). More than 60,100 field data were collected from 49 lines that had a cumulative length of almost 4.8 km.

3. ERT Data Processing

The topography along each line was extracted from the Digital Elevation Model and was used to correct the data for the topography effect. Inspection of apparent resistivity values for the 49 lines showed that Mound B was characterized by a mean apparent resistivity value of 32.4 Ohm-m. The poor contact of some metal stakes with the ground or the disconnection of the cable with a relevant electrode resulted in extremely high or low resistivity values that were removed from the collected data set. The data points that exhibited standard deviation errors more than 1% were removed from the data. A second stage filtering was performed by compressing the dynamic range of the apparent resistivity values within the range of 10–200 Ohm-m.

At first all the individual lines were processed with a 2D resistivity inversion software that can incorporate the topography of the mound along a specific line, in order to reconstruct vertical resistivity models along each profile. Similar inversion parameters were used for the data processing. The final inverted models exhibited similar and relatively low RMS errors (2.2–3.9%). The resistivity models along each line were visualized with a common color logarithmic where the blue and red colors indicate areas of low and high resistivity variation respectively.

The next processing stage included the compilation of horizontal slices at different depth levels within the Mound by approaching the data with a full 3D resistivity inversion algorithm. This was accomplished by integrating all the individual profiles to a single file where the 3D subsurface apparent resistivity variation of the mound was described by more than 43,400 measurements. The subsurface of the mound was divided in 43,200 [(X, Y, Z)=(50, 48, 18)] rectangular blocks that described the true subsurface resistivity. The inversion program converged to a final resistivity model after 6 iterations with RMS= 5.5%.

4. ERT Results

The western most lines (L49 to L42 – X=320–334m) and eastern most profiles (L08 to L01 – X=402–416m), that were laid out on the flat part of the mound, exhibit similar tomographic images. The vertical stratigraphy along these lines is composed of three distinct horizontal layers that are registered in the inversion models with different resistivity values (Fig. 3). The uppermost high resistivity layer *(50–350 Ohm-m)* has a thickness of 2.5–3.0 m and represents the recent geologic and anthropogenic deposits. Bellow this resistive layer a distinct area with lower resistivity values *(3–50 Ohm-m)* signify the existence of a clay/silty clay layer with an average thickness of 7.0–7.5 m. Below the mean absolute elevation of 62–63 m a high resistivity layer *(40–350 Ohm-m)* is correlated with a relatively more grained material (silty/clayey sand – sand) that corresponds to “bedrock”. This layer is evident in all ERT profiles.

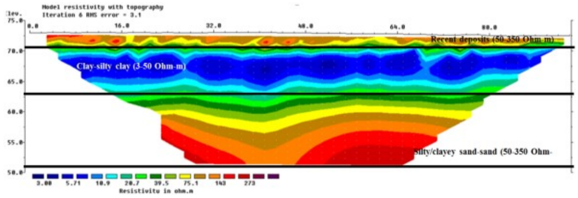

Figure 3 A representative tomographic resistivity model of the lines that were laid out along the westernmost and easternmost flat area of the mound. The interpretation of the vertical layers that compose the stratigraphy is also shown.

Towards the central part of the mound, ERT profiles show a more complex stratigraphic architecture by diverging from the three-layer stratigraphy. Lines L41 to L09 (X=336–400 m) show local inhomogeneity within the topmost layer and the underlying silty clay layer. For example lines L41 to L37 (X=336–344 m) show a discontinuity in the uppermost high-resistivity layer in the central part of the mound (horizontal distance: 48–56 m). In Lines L36 to L34 (X=346–350 m) the silty clay layer below the elevated part of the mound seems to be interrupted by a higher resistivity material (~30–40 Ohm-m) and is divided into a northern and southern section along the profiles (Fig. 4 top).

From the line L33 (X=352 m), an ellipsoidal area with relatively lower resistivity signature (~30 Ohm-m) starts to appear below the uppermost high resistivity layer on the northern slope of the profiles. This area continues with relatively same resistivity values but further shifted to north of the profiles, until the line L28 (X=362 m). It seems to be interrupted along the line L27 (X=364 m), but within the lines L26 to L18 (X=366–382 m) the same zone of high resistivity appears again with relatively lower resistivity value (~20 Ohm-m). At the same time, the interruption of the silty clay layer is also obvious within these profiles (Fig. 4 bottom). Finally the lines L17 to L09 (X=384–400 m) continue to have local in homogeneities which fade away as we move towards the eastern profiles approaching the flat area of the mound.

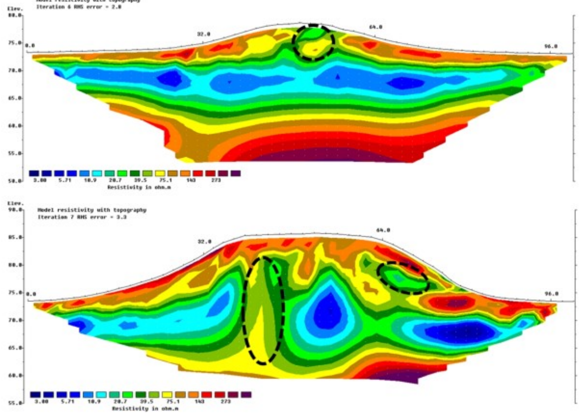

Figure 4 Top: Differentiation of the resistivity material property within the topmost resistive layer as the ERT profiles start to cross the elevated part of the mound. Bottom: Outline of the ellipsoidal low-resistivity anomaly at the northern part of the ERT profiles (below the top most high resistivity layer) and the discontinuity of the silty clay layer.

The analysis of the 2D resistivity profiles provided significant information regarding the vertical stratigraphy of the mound. In a second stage all the lines were merged and processed within a 3D context in order to produce horizontal resistivity slices that describe the extent of the subsurface features at different depths or elevations (Fig. 5).

The horizontal depth slices (Fig. 5) can give a general picture of the mound's filling material. It seems that within the absolute elevations between 85 m to 80 m (Z=0–5 m) the mound is composed of a coarse-grained material with resistivity values more than 70 Ohm-m. Local inhomogeneities of relatively larger resistivity values appear between the elevations of 8 m to 83 m (Z=0–3m). Below 79 m (Z=6 m) the material becomes finer as it consists of silty clay with resistivity values less than 5 Ohm-m. This rough vertical differentiation in the layers' stratigraphy indicates at least two different construction phases during the history of the mound.

The prominent low resistivity anomaly at the north-east corner of the survey grid (depth layers Z=0–3m) is a by-product of the inversion processing due to the lack of data in this region. This is due to the length of the ERT profiles that was shorter and did not the end of the grid in the specific locations. Furthermore it is well known that the resolution of the ERT survey decreases with increasing depth from the surface, while the resolvable power of the inverted image is minimum at the edges of the grid due to the specific layout of the south-north ERT profiles that were assembled to create the 3D resistivity model.

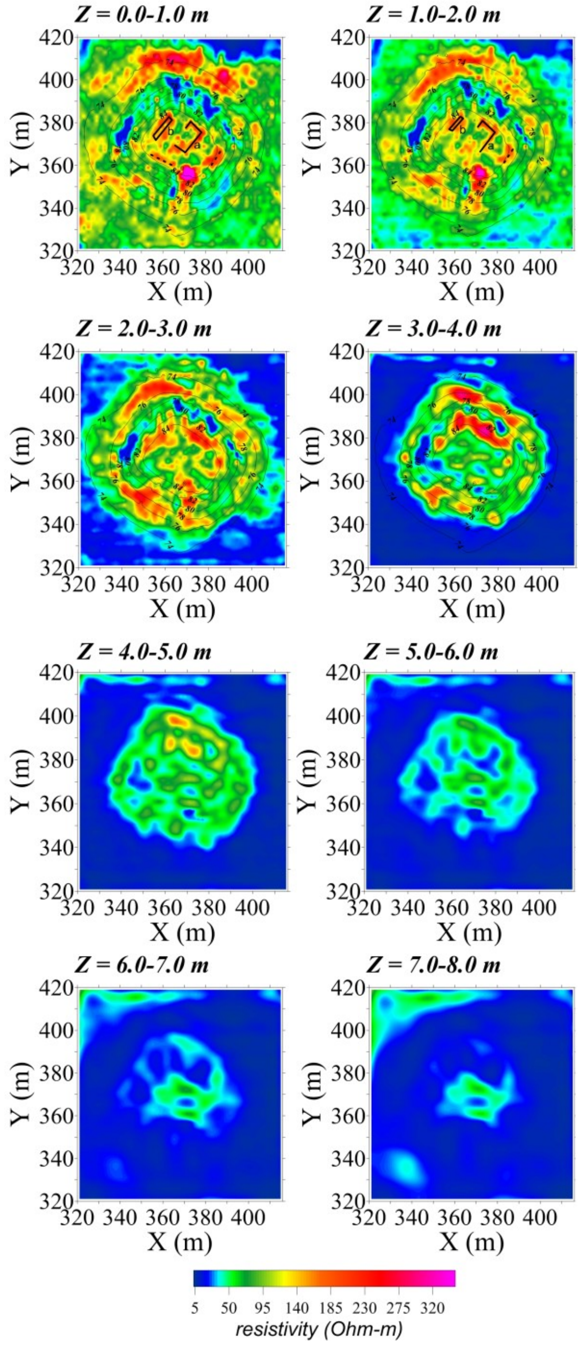

Figure 5 Horizontal depth slices up to 8 meters depth from the ground surface (elevations 85 m to 77 m) that were extracted from the 3D resistivity inversion model. The elevation lines every 2 m from the digital elevation model of the mound have been superimposed on the resistivity images.

Regarding the more superficial features, the depth slices up to Z=3 m are quite informative. A prominent high-resistivity rectangular anomaly (a) is registered within the first depth slice (Z=0–1 m) on the top center part of the mound. The feature has a NE-SW orientation and maximum dimension of 12.5 x 7.5 m while it seems to continue up to a depth of 2 ms below the ground surface. Another linear high resistivity feature, with a length of ~8–9 m (Fig. 5, feature b) lies about 10 meters north west of feature a (Fig. 5, feature a) having the same orientation with it.

One of the dashed lines represents a high resistivity region in the eastern part of the top of the mound (Fig. 5). This area is probably related to features (a) and (b) since it has the same orientation with them, but it should be treated carefully as it lies on the edge of the mound. The second dashed line on the top of the mound is perpendicular (NW-SE) to the previous anomalies. This area may be related to a “shaft” that was dug on the summit of the mound during the early 1880s when the top of the mound was cultivated as a garden (Rolingson 2012, 199).

The 1979 excavation trench has also been identified in the geophysical maps as an almost circular area with increased resistivity values exactly to the south of anomaly (a). This extends at the south slope of the mound and coincides quite well with the erosion cut seen in a picture of 1979 excavation program (Rolingson 2012, 201, fig. 154). The depth slices also indicate a circular low resistivity region (probably a ditch) that surrounds the west, north and east periphery of the mound. This region roughly follows 78 m contour line around the mound and appears to have a maximum thickness of about 4 meters.

Finally an effort was made to correlate the excavation profile from the 1979 field excavation project (Rolingson 2012, 202, fig. 156) with a respective 2D ERT section extracted by the 3d resistivity inversion model (X=342m). The results turned out to be inconclusive, as we were not able to correlate the layers exposed by the excavation and the geoelectrical image in the specific portion of the profile. This is due to the relatively large spacing (2 m) that was used to collect the ERT data in contrast to the fine details that can be defined through the excavation process.

Conclusions

The purpose of this research was to explore the subsurface of one of the Toltec's tallest archaeological mounds. Very little was known about this impressive structure regarding its stratigraphy, and purpose, due to a lack of resources and a preservation ethic which prevents excavation.

Electrical Resistivity Tomography contributed in the compilation of a 3D resistivity model the archaeological mound B in Toltec Archaeological State Park. Through this method, we were able to define the whole sequence of the filling material of the mound with considerable accuracy based on the resolution of the field measurements Resistivity sections and slices show that the archaeological mound is primarily composed of a low resistivity clay material that was capped with a two to three meter thick layer of high resistivity material, likely a silty loam, over the entirety of the mound surface. Archaeological excavations (Palmer 1990) appear to confirm these results, and also provide assurance that this addition was indeed a prehistoric one. This fact indicates of at least two separate construction phases for the Mound.

The high resistivity unit that is detected at the north of the mound in the horizontal slices (Z=0–4 m) indicates the location of an off-mound midden (Horton personal communication). Furthermore the survey managed to delineate rectangular structures in the upper part of the mound that could be attributed to structural historical remains.

In general the results of this work demonstrate the importance of tomographic resistivity techniques in the reconstruction of the stratigraphical architecture of man-made earth mounds especially in cases where traditional mapping geophysical methods are inadequate to extract information from deeper stratigraphical levels.

Acknowledgements

The geophysical survey was conducted under the framework of the Fulbright Research Scholarship granted to Dr. Nikos Papadopoulos by the Fulbright Foundation for the academic year 2012–2013. Special acknowledgements have to be given to the Arkansas Archeological Survey (Dr. Tom Green) and the Arkansas State Park (Mr. Randy Robertson, Manager of Planning and Development) for allocating the funds to rent the appropriate geophysical instrumentation. The field measurements wouldn’t have been completed in time without the valuable and constant help that was provided by the numerous graduate and undergraduate students from the department of Anthropology of The University of Arkansas who participated in the field campaign.

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LAND CHANGE IN CRETE: ANALYSIS AND PREDICTION USING CORINE LAND-COVER DATA AND IDRISI LAND CHANGE MODELER

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Περίληψη/ Abstract

Δεδομένου ότι η αλλαγή της γης συνεχίζει να έχει δραστικά αποτελέσματα για τους φυσικούς οικότοπους, αλλά και για περιοχές αρχαιολογικού ενδιαφέροντος και πολιτιστικής κληρονομιάς, η κατανόηση ενός μεταβαλλόμενου τοπίου ενισχύει το σχεδιασμό, τη διαχείριση και την προστασία των συγκεκριμένων οικοτόπων. Η κατανόηση αυτών των περιβαλλοντικών και ανθρωπογενών διεργασιών με τη βοήθεια των GIS και της τηλεπισκόπησης μπορεί να οδηγήσει σε μία μοντελοποίηση της πιθανής εξέλιξης της χρήσης γης. Η μελέτη αυτή βασίστηκε στο εργαλείο Land Change Modeler του λογισμικού της Idrisi και η κάλυψης γης πραγματοποιήθηκε με στατιστική ανάλυση με βάση τον πίνακα Συσχέτισης με τη χρήση των δεδομένων Corine Land-cover. Δεδομένου ότι αυτή η έρευνα παρέχει μια σε βάθος ανάλυση για την αλλαγή χρήσης και πιθανή υποβάθμιση της γης για ολόκληρο το νησί της Κρήτης, αποτελεί ταυτόχρονα ένα πρώτο βήμα για την περαιτέρω διαχείριση και προστασία της πολιτιστικής κληρονομιάς.

As land-cover change continues to have drastic results on natural habitats, livelihoods and also archaeological and heritage sites, comprehension of a changing landscape aids in planning, management and prevention. The modelling of land-cover variations with the aid of GIS and remote sensing leads to a deeper understanding of the environmental and anthropogenic processes that can lead to specific changes. While there is a plethora of options and analyses related to the modelling of land-cover, this study relies on the Idrisi Land Change Modeler and a land-cover statistical analysis based on the Cross-Tabulation matrix and Corine Land-cover data. As this research provides an in depth analysis of land-cover change and possible land degradation of Crete, it represents a first step in future archaeological or heritage site management.

Keywords: Land-cover Classification, Corine Land-cover Data, Idrisi Land Change Modeler, Intensity Analysis

Introduction

Land use land cover change remains an inevitable process in any landscape. GIS and remote sensing enable us to interrogate these changes to reveal underlying processes, ultimately leading to possible conclusions regarding the causes and influences of land change. As land change only becomes more relevant in a changing and environmentally fragile world, projecting environmental change through the prism of today's landscape influenced by specific factors can serve as a useful prediction tool to aid in planning land management.

In Crete, changing urban centres and expanding populations have led to changes in agriculture and land-use, namely more extensive and more intensive exploitation of resources (Sarris *et al*. 2005). As such, the land has become more and more fragmented as population pressures push outward from city centres. As urban populations expand into rural areas, peri-urban areas or areas of transition can indicate direct impacts of land change, urban growth and pollution (Douglas 2006, Fang *et al*. 2005). This preliminary study investigates the changing land-cover of Crete for multiple time intervals based on the Corine land-cover classification.

Using Corine land-cover classification data for Crete, this study evaluates the land change from one land-cover class to another over a period of ten years, 1990-2000. To understand the changes between categories, the cross-tabulation matrix evaluates pixel changes between land-use category and time interval. Following an analysis of the type of apparent land-use changes in this time period, the interest is to understand the trajectory in the future. This study uses the Land Change Modeler of Idrisi Selva (Idrisi Selva, 2014. Clark Labs/ http://www.clarklabs.org/) to predict urban and vegetation cover of Crete for the present date of 2013 and the future date of 2030. This land-cover change model proved successful in identifying periods of land-cover transitions as seen in similar studies mapping the urban expansion (Gallardo and Vega 2011, Onojeghuo *et al*. 2013). Ultimately, these types of analysis can be coupled with planning data and archaeological data to enable sustainable heritage management plans.

1. Methodology

The methodology is comprised of multiple steps including pre-processing, pixel change analysis, land change prediction and accuracy assessment. These different processes are detailed below in 1a–1c for the interval of 1990–2000. The process was repeated for 2000–2013. A final step uses the same methodology to predict the results of land cover change for the year 2030. Satellite images used for this analysis are the Corine land-cover data, consisting of georeferenced and classified land-cover of Europe for the years 1990 and 2000. The database is available for download from the European Environment Agency (European Environment Agency 2013). The Corine Land-cover data is derived from the classification of Landsat TM satellite data. While there is a 2006 data set now available, there is no coverage for Greece for this specific period.

1.a Data Pre-processing: Corine Land-cover Classification

Corine Land-cover data have been successfully implemented for environmental assessment projects despite the limited spatial resolution of the Landsat TM data (Grullon *et al.* 2009). The extracted dataset for the area of Crete contains 44 different land classes stemming from four major land classes - built, forest, agriculture and water. Detailed land-cover classes of the images would lead to less accurate results, so the 44 classes were grouped into nine major classes. The nine categories are: urban, arable fields, pastures, permanent crops, heterogeneous fields, forest, shrubs, barren and water (Karydas 2013). Figure 1 and Figure 2 show the classified land cover images of Crete in 1990 and 2000.

1.b Cross-Tabulation Matrix and Intensity Analysis

The land cover change is evaluated by a comparison of pixel differences or additions of the first date (1990) to the second date (2000) through a cross-tabulation matrix. The pixels from the cross tabulation matrix are then entered into Intensity analysis (Pontius *et al.* 2004). This procedure evaluates the exchanges between pixels of different classes, as well as the observed commission and omission error and finally the validity of the kappa value in the land-cover classification (Pontius & Millones 2011).

Intensity analysis is useful to understand land change through time (Pontius *et al.* 2013). Through Intensity Analysis, the transition matrix, created through cross tabulation, is interrogated to reveal detailed land cover patterns that could be lost if analysis is based purely on total percentages of land-cover categories. The ten year period or interval is analysed by breaking down the categories into commission, omission, or persistence. A commission pixel represents a pixel that is a land cover category in the end date or comparison map that differs from the land cover category in the start date or reference map. An omission pixel is one that belongs to a land cover category in the start date or reference map and changes land cover category in the end date or comparison map (Pontius & Millones 2011). A pixel is persistent if it stays the same throughout the time interval. Intensity analysis also reveals how relatively fast or slow annual land cover change occurs. Finally, this is expanded upon as each land cover category can be determined as active, dormant or stable during an interval (Pontius & Millones 2011).

1.c Land Change Modeler

Using the Land Change Modeler of Idrisi, the first image of 1990 is identified as the start date and the 2000 image is identified as the end date, leading to the creation of transition maps (loss, persistence and gain) of land class categories. From these transition maps, it is possible to understand the changes of specific land-cover classes in a given period. It becomes apparent that the land-cover class heterogeneous crops experienced growth throughout the ten year period. The categories of arable and water classes are not displayed as they were not contributors to land changes observed in that period.

2. Results

The results of the land change analysis according to intensity analysis, land change modeler are described below according to each time period (1990–2000 or 2000–2013).

2.a Results of 1990–2000 Land Cover Change

Table 1a indicates the values in the cross tabulation matrix used to calculate the intensity analysis of the 1990–2000 period. Table 1b indicates the intensity of change for the categories of land-cover in the period 1990–2000. The dashed line in Table 1b indicates whether a category is active (to the right) or dormant (to the left) in change. We observe that only the urban category is active and specifically, active in commission (value: 14). This indicates that the urban land-cover class is being produced by the loss of pixels from other land categories that switch to urban, giving more pixels of urban class at the end date of 2000 than the start date of 1990. This land-cover change process is occurring at a more accelerated rate than the other land change processes. Heterogeneous crops class is also exhibiting commission or gaining pixels by other land categories and contributes to other land-cover classes (value: 5). The Pastures category is almost as active as the Urban category, but an entirely different land change process is occurring (value: 11). Pixels of the pastures category is switching to other land-cover categories. This would suggest that open land is being converted to other land-use types. We can see finally the total percentage that each land cover category comprises for the whole of Crete in Table 1c. The results indicate that Shrubs occupy a large amount of Crete (47%), followed by Permanent Crops (27%).

2.b Results of Land Change Modeler (1990–2000)

Having mapped the transitions (loss, persistence and gain) of land-cover categories for 1990–2000, the next step was to run the model in order to produce future transition potentials for the study area for the year 2013. This image would be used to complete the analysis of land cover change from 2000–2013. The transitions of interest are changes to urban and peri-urban areas or areas with urban and rural fragments juxtaposed. 2013 was selected as the prediction date, since the results could be visually verified in Erdas Imagine (http://www.hexagongeospatial.com) with present day satellite imagery from Google Earth. The results suggest that most changes in land-cover have occurred around urban areas and touristic areas of the coast. Few changes have taken place in barren landscapes as they tend to be associated with mountainous regions.

2.c Results of 2000–2013 Land-cover change

To visualize and then analyse the land-cover changes for the period of 2000–2013, the previous steps of Cross-Tabulation matrix, Land Change Modeler and Intensity Analysis were repeated with the newly produced 2013 image from the above step, 2.b. From the Cross-Tabulation Matrix and Intensity analysis in Table 2a and Table 2b, we investigate the changing land use for this period. The cross tabulation matrix of the 2000 image and the newly formed 2013 image is represented in Table 2a. In Table 2b, we see the commission and omission of the different categories. There are few instances of swap between categories. Only the Heterogeneous Crops category exhibits pixels of both omission (value: less than 1) and commission (value: 6). The Heterogeneous Crops and Urban (value: 2) categories are both represented by the commission of pixels. Pastures (value: 14) is the only land-cover class that is active and in this case, active in omission of pixels. Only the Pastures category has changed at a non-uniform rate compared to the rest of the land categories, although in general, the land-cover percentage of Pastures class is actually quite small in comparison with the rest of the land-cover categories. To verify the results of this, an accuracy assessment was accomplished.

What makes these results interesting is when they are compared to the total land cover of Crete seen in Table 2c. This table reveals the percentage that each land cover category comprises. In this table we see that Shrubs makes up the largest part of the land-cover (46%). Permanent Crops class is still one of the largest contributors to the land-cover (26%). Heterogeneous Crops has grown one percent from 15 to 16%. If viewed on its own or in comparison to table 1c., these results could misleading as there appears to be relatively no change, when in fact, the intensity analysis reveals much has occurred.

3. Accuracy Assessment

As there was no recent land-cover layer of Crete available, it was decided to use Google Earth images to perform an accuracy assessment of the newly produced 2013 image from Land Change Modeler. Using Erdas Imagine, 100 random points were chosen from the 2013 thematic land-cover prediction map created by the Land Change Modeler. These points were compared with the actual land-cover seen in the satellite imagery from Google Earth. Obviously, this method is not completely accurate as the two images were not linked spatially and Google Earth contains much more detail than the Landsat TM Corine Land-cover data, but it did provide a visual assessment of the Land Change modeler prediction. This gave an overall classification accuracy of 91.00% and a Kappa Statistics of 0.87. Most confusion existed with the land-cover classes Shrubs, Permanent Crops, and Heterogeneous crops, which are difficult to recognize in Google Earth. While the overall classification accuracy is quite high, it is understood that this method of accuracy assessment is very limited. For a better understanding of the changes predicted, it would be best to use a validation layer that could be more comparable with the Corine land-cover data.

4. Next Steps: Land-cover Prediction of 2030

Since the accuracy assessment of the forecast 2013 land-cover indicated acceptable results, it was decided to predict the land-cover of 2030 using the 2013 image as a start date image. The resulting image of the predicted 2030 Land-cover of Crete (Fig. 3) would suggest that drastic changes are not predicted for the future trajectory.

Using the same methodology as the previous intervals of 1990–2000 and 2000–2013, the changes during the 17-year period were evaluated (Table 3a,

Table 3b, and Table 3c). The results are consistent with the tendencies observed in the two previous time intervals of 1990–2000 and 2000–2013. The corresponding Intensity Analysis of 2013–2030 suggests an increasing rate of change (Table 3b), perhaps a consequence of the larger time interval (of 17 years). Similar to the 2000-2013 period, Pastures (value: 18) are active in omission compared to the rest of the land categories and Heterogeneous crops (value: 7) and Urban (value: 2) continue to be almost purely based on commission. This indicates that Urban and Heterogeneous crops will continue to occupy a larger part of the landscape. Further, the active change seen in Pastures is indicative of a quickly changing landscape- one that sees open fields being converted to other types of land cover.

Again, we also investigate total land cover percentages as with the intervals of 1990–2000 and 2000–2013. In Table 3c, we see the category Shrubs is consistently the largest land-cover of Crete (27%), followed by the category of Agriculture, made up of Permanent Crops (26%) and Heterogeneous Crops (15%), as the two more abundant land-covers. However, this does not reveal the detailed patterns of change that are present in the Intensity Analysis.

Conclusions

Advanced methods of satellite imagery analysis provide tools for a better management and planning of the landscape. Satellite imagery coupled with Idrisi Land-cover Modeler provide a useful environmental analysis technique as the user controls variables and inputs. In addition, this analysis considers detailed changes present in a time series. Rather than simply relying on kappa values or total percentage, use of the cross-tabulation matrix as a basis for an in-depth analysis of pixel data provides useful and meaningful results instead of false notions about land change.

One has to take into account the accuracy of the results. Even though the classification models provided similar levels of accuracy (despite the high variability of land-cover in Crete), an accuracy assessment of the land cover change modelled is difficult due to the lack of recent data or satellite images. Furthermore, it is clear that land-cover analysis using Landsat TM satellite data does not provide the detail and resolution needed to draw conclusions on a local scale. Despite this, all results indicate a constant expansion of both urban areas and agricultural lands that seem to continue to 2030. This indicates change or increasing intensification of agricultural practices in the region. Current agricultural production in Crete has seen a shift from less traditional forms of agriculture to more complex agricultural processes of growing and production (Sarris *et al.* 2005). The procedure is simple to use and the output provides much useful data about land-cover change.

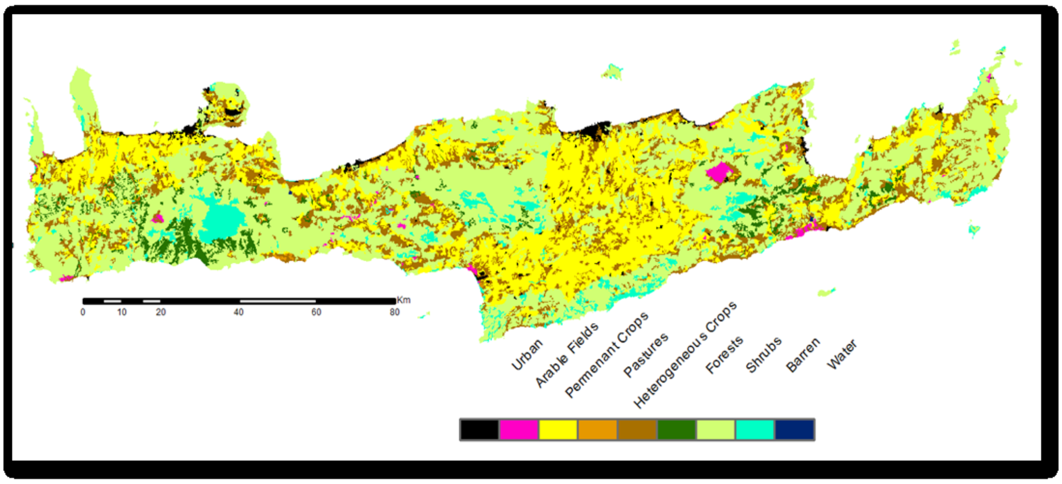

Figure 1. 1990 Corine land-cover data, Crete

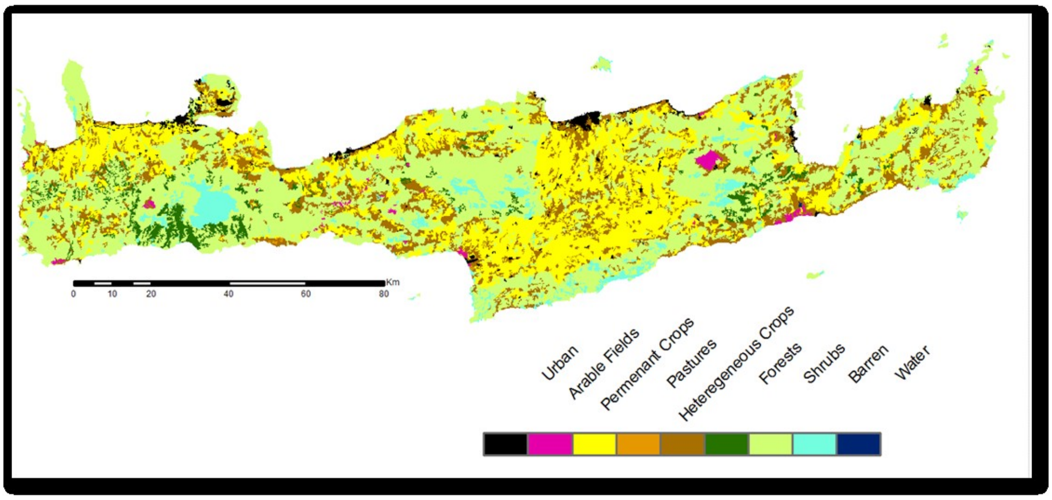

Figure 2. 2000 Corine land-cover data, Crete

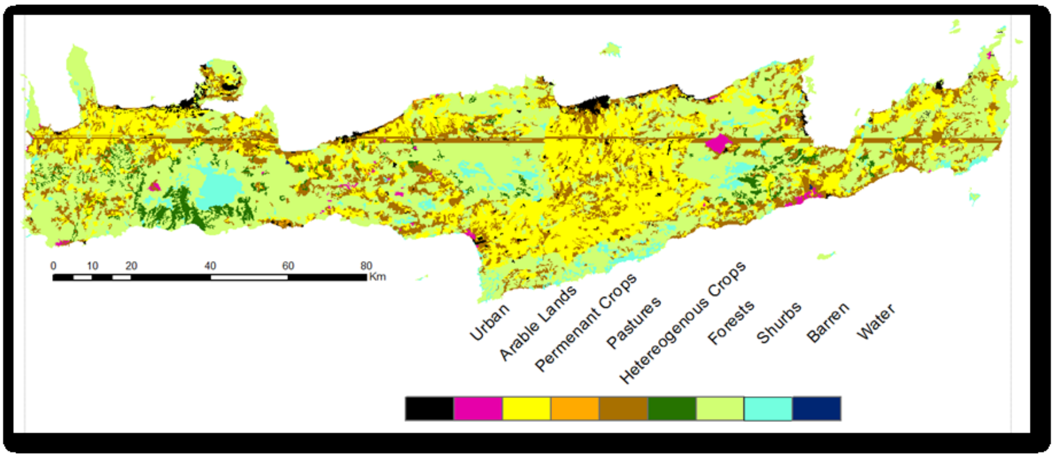

Figure 3. 2030 Projected Land-cover using Idrisi Land Change Modeler

		2000 Urban	2000 Arable	2000 Permanent Crops	2000 Pastures	2000 Heterogeneous Crops	2000 Forests	2000 Shrubs	2000 Barren	2000 Water
1990	Urban	11114	0	442	0	185	1	1123	2	0
1990	Arable	0	5158	4	4	16	0	59	0	0
1990	Permanent Crops	0	0	219782	0	405	14	880	30	0
1990	Pastures	0	0	0	1651	0	0	0	0	0
1990	Heterogeneous Crops	7	0	1760	199	123205	175	3919	16	0
1990	Forests	0	0	0	0	0	28312	12	0	0
1990	Shrubs	0	0	5	0	49	1725	393157	712	0
1990	Barren	0	0	0	0	0	0	85	34596	0
1900	Water	0	0	0	0	0	0	0	0	144

Table 1a 1990–2000 Cross Tabulation Matrix

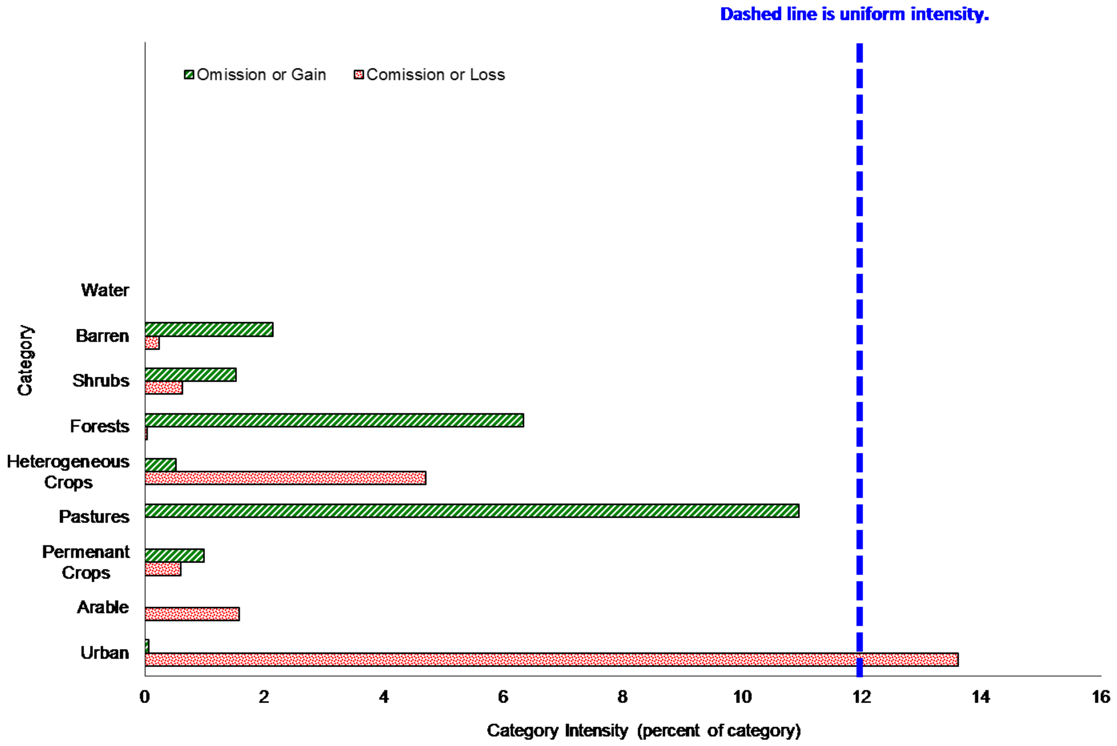

Table 1b 1990–2000 Intensity Analysis

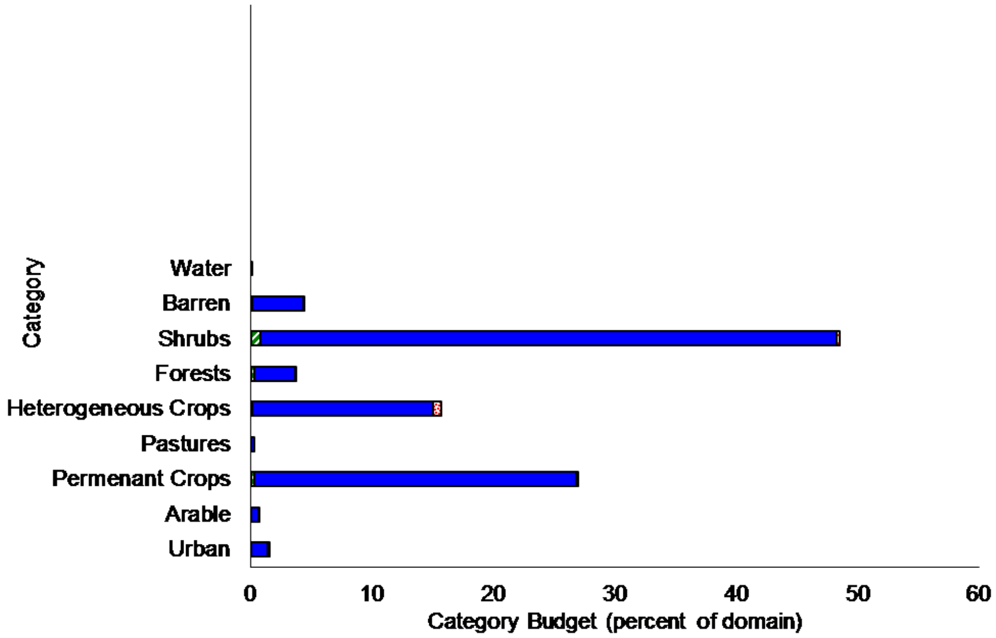

Table 1c 1990–2000 Total Land Cover Percentages

		2013 Urban	2013 Arable	2013 Permanent Crops	2013 Pasture	2013 Hetero-geneous Crops	2013 Forests	2013 Shrubs	2013 Barren	2013 Water
2000	Urban	12867	0	0	0	251	0	0	0	0
2000	Arable	0	5241	0	0	0	0	0	0	0
2000	Permanent Crops	0	0	218837	0	0	0	0	0	0
2000	Pastures	0	0	0	1424	0	0	0	0	0
2000	Hetero-geneous Crops	0	0	2274	227	129030	214	5035	0	0
2000	Forests	0	0	0	0	0	28110	0	0	0
2000	Shrubs	0	0	0	0	0	0	390613	0	0
2000	Barren	0	0	0	0	0	0	0	34681	0
2000	Water	0	0	0	0	0	0	0	0	144

Table 2a 2000–2013 Cross Tabulation Matrix

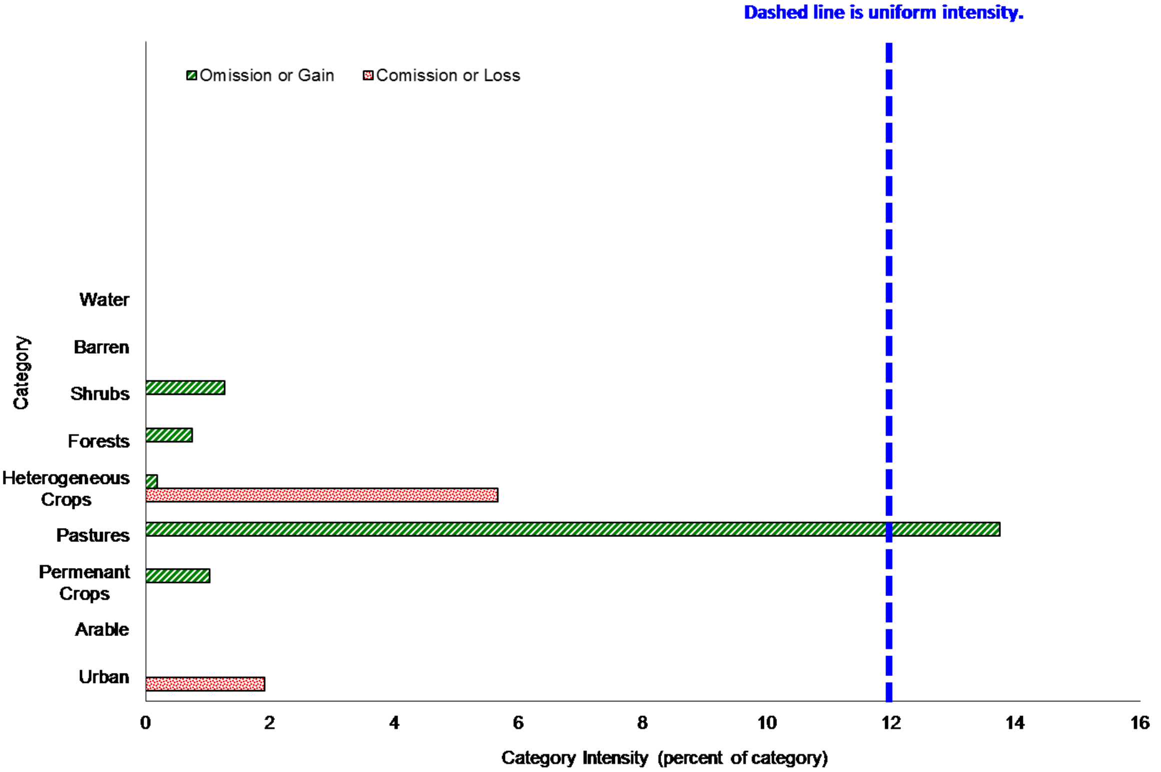

Table 2b 2000–2013 Intensity Analysis

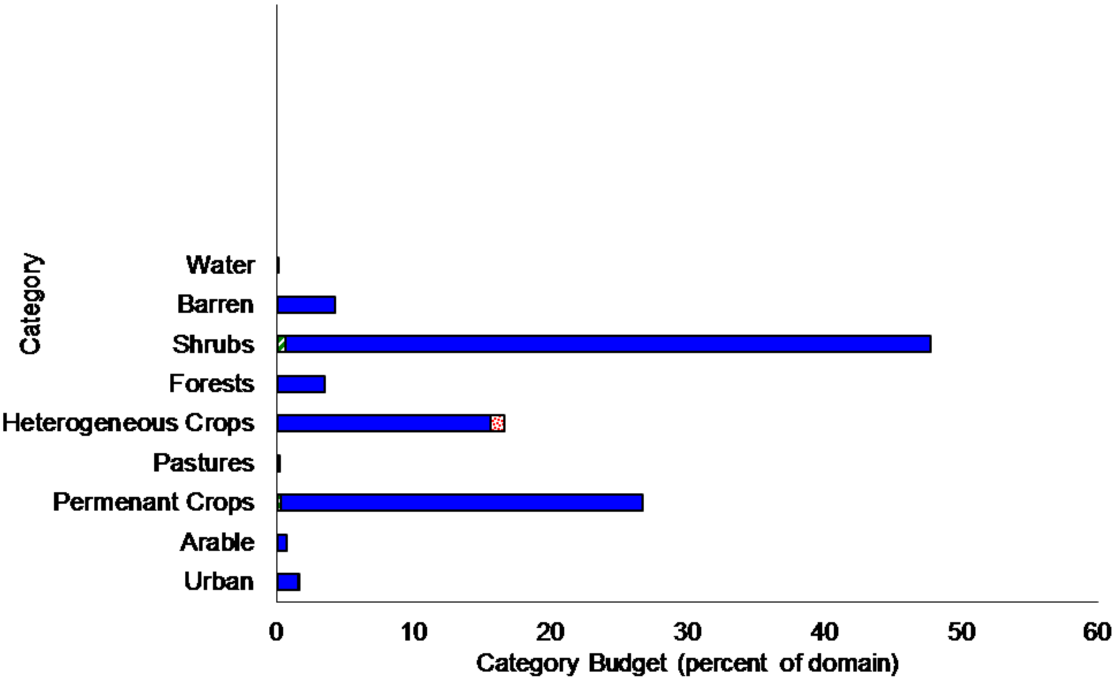

Table 2c 2000–2013 Total Land Cover Percentages

		2030	2030	2030	2030	2030	2030	2030	2030	2030
		Urban	Arable	Permeant Crops	Pastures	Heterogeneous Crops	Forests	Shrubs	Barren	Water
2013	Urban	13118	0	0	0	331	0	0	0	0
2013	Arable	0	5241	0	0	0	0	0	0	0
2013	Permeant Crops	0	0	215893	0	44	0	0	0	0
2013	Pastures	0	0	0	1178	0	0	0	0	0
2013	Heterogeneous Crops	0	0	2944	246	136405	290	6399	0	0
2013	Forests	0	0	0	0	0	27820	0	0	0
2013	Shrubs	0	0	0	0	0	0	384214	0	0
2013	Barren	0	0	0	0	0	0	0	34681	0
2013	Water	0	0	0	0	0	0	0	0	144

Table 3a 2013–2030 Cross Tabulation Matrix

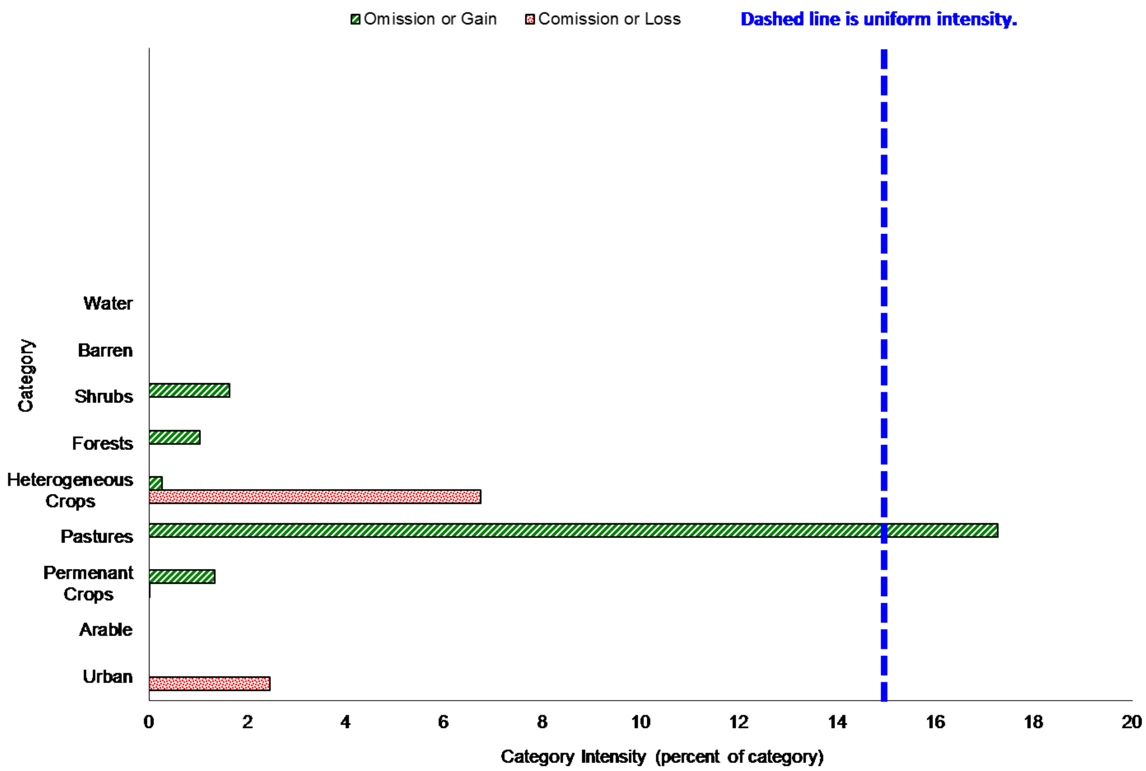

Table 3b 2013–20130 Intensity Analysis

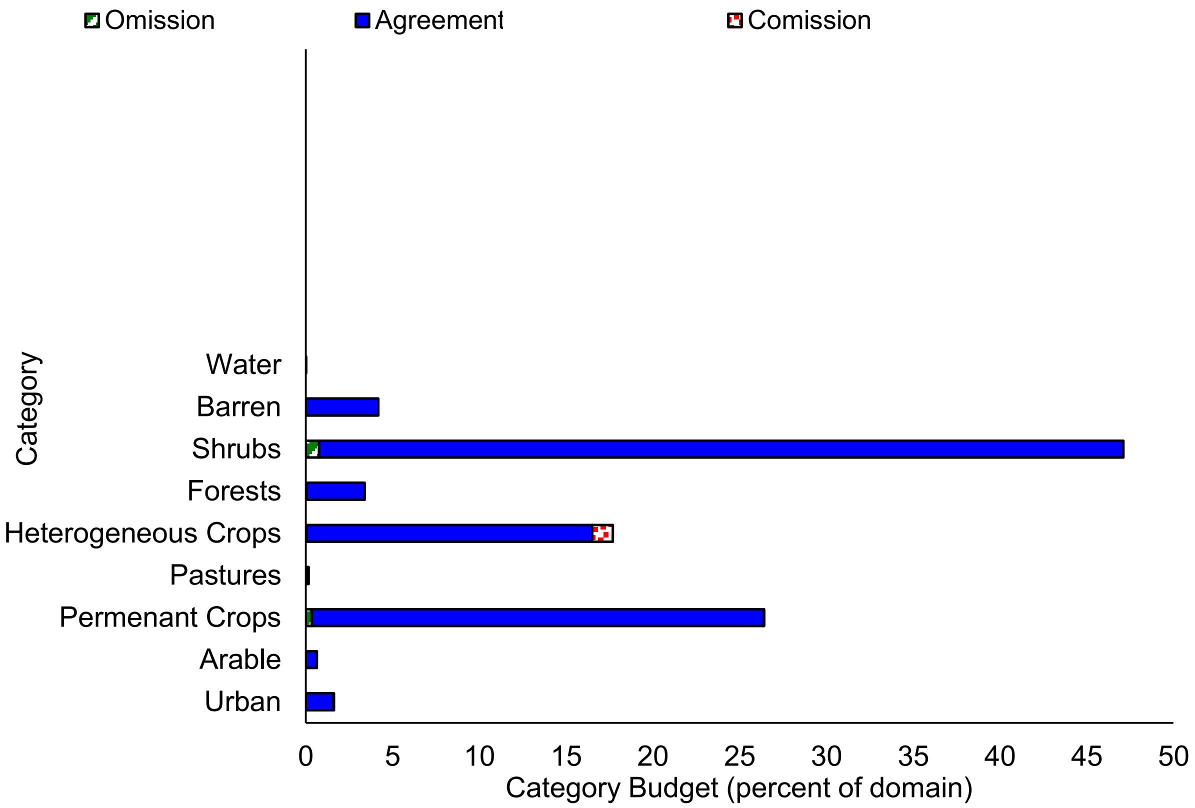

Table 3c 2013–2030 Total Land Cover Percentages

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AN OPEN SOURCE GIS APPLICATION FOR THE STUDY OF SETTLEMENT PATTERNS IN LATE ANTIQUE AND EARLY BYZANTINE CRETE

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Περίληψη/ Abstract

Στην παρούσα εργασία παρουσιάζεται μια εφαρμογή GIS ανοικτού κώδικα για τη μελέτη των οικιστικών διατάξεων στην Κρήτη κατά την υστερορωμαϊκή και την πρωτοβυζαντινή περίοδο (365–827 μ.Χ.), με βάση μια συνεχή και συστηματική συλλογή όλων των δημοσιευμένων αρχαιολογικών δεδομένων για τα κατάλοιπα των οικισμών στην Κρήτη κατά την εξεταζόμενη περίοδο. Στο πλαίσιο αυτό, αναπτύχθηκαν μια σχεσιακή γεωγραφική βάση δεδομένων και μια εφαρμογή GIS χρησιμοποιώντας τα λογισμικά QGIS και SpatiaLite για τη συλλογή, διαχείριση και αναζήτηση αυτών των δεδομένων: γεωγραφικές συντεταγμένες, χρονολόγηση, κατηγορία και μέγεθος του οικισμού, λεπτομερή αρχαιολογικά στοιχεία, βιβλιογραφικές αναφορές. Όλες αυτές οι τυπολογίες δεδομένων παρουσιάζουν προβλήματα αβεβαιότητας και αντιπροσωπευτικότητας, τα οποία συζητούνται στη μελέτη. Το λογισμικόQGIS σε συνδυασμό με το SpatiaLite αποδείχθηκαν ικανά να λειτουργήσουν ως μια ολοκληρωμένη πλατφόρμα για την καταγραφή των δεδομένων αλλά και ως πλατφόρμα διερεύνησης ερμηνευτικών μοντέλων.

We present an application of standard open source GIS tools to the study of settlement patterns in Crete in the Late Roman and Early Byzantine period (365–827 AD), based on an ongoing systematic collection of all published data about archaeological evidence of human settlements in Crete during the period under examination. We developed a relational geodatabase and GIS application using QGIS and SpatiaLite to collect, manage and query this growing collection: geographic coordinates, chronology of occupation, settlement type and size, more detailed archaeological evidence, bibliographic references. All these data types can have problems of uncertainty and representativity that we discuss. We found QGIS together with SpatiaLite capable of acting as a complete platform to record data and also as a testbed of interpretative models.

Keywords: Crete, Late Roman, Early Byzantine, Open Source GIS, settlement patterns

Introduction

Late Roman and Early Byzantine Crete has become a subject of scholarly interest only in the past three decades. At the same time, a substantial increase in quality and quantity of archaeological data has resulted from rescue and preventive archaeology, together with a few large excavations focused on the "late" period, under the influence of new developments in Mediterranean archaeology.

Minoan Crete has always been the main subject of Cretan archaeology: unsurprisingly, the first systematic overview of the Roman and Early Byzantine period is Ian Sanders's *Roman Crete* (1982), a pioneering work, still necessary even though it is now outdated both in its contents and methodology. Sanders had proposed a jonesian model (see e.g. Zavagno 2009, 8) for settlement patterns in Crete from the Late Hellenistic period to the Arab conquest (actually, rather the mid-7th century), in which the Early Byzantine period was nothing more than the final chapter of Antiquity. Thirty years of archaeological research in Crete and the Mediterranean have now significantly changed our perspective and it seems now natural to focus on this period as a self-standing subject, with its own features in both cities and the countryside.

The Late Roman and Early Byzantine period in Crete is traditionally dated between 365 and 827 AD, without a clear separation between the two. The chronological boundaries are respectively those of the major 365 AD earthquake (Stiros 2010) and the final Arab occupation of Crete (Christides 1984). The former event provides a horizon that is common for most archaeological sites on the island, while the latter marks a conventional date for the end of occupation in many settlements. During these five centuries, settlement patterns changed significantly, together with land use and exploitation of natural resources, leading to a fragmented landscape of virtually separate regions. After the hiatus of 827–961 AD (Emirate of Crete), for which little archaeological evidence is available, the settlement pattern of the Second Byzantine period in Crete is very different (Tsougarakis 1988).

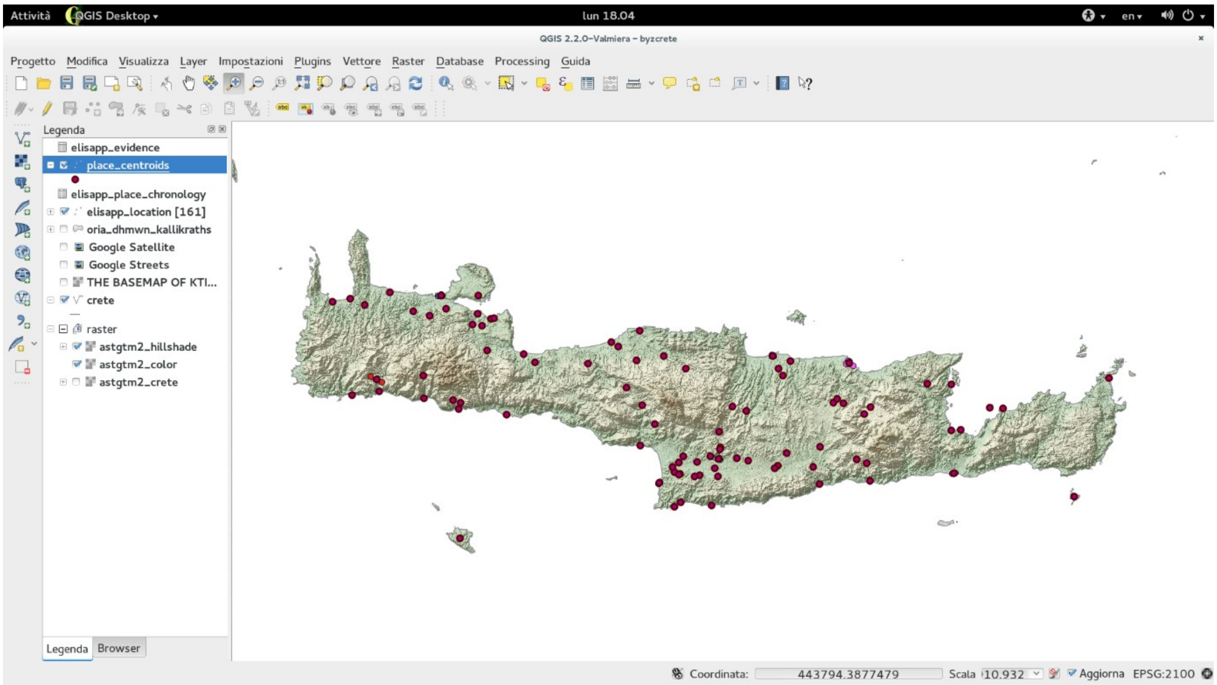

Figure 1 A screenshot of the main QGIS window with the sites recorded so far.

In order to build updated models, we needed to re-examine a substantial amount of archaeological data with state-of-the-art techniques. The work we present here is based on a still ongoing systematic collection of all published data about archaeological evidence of human settlements in Crete during the period under examination. To collect, manage and query this growing collection we developed a relational geodatabase and GIS application using QGIS and SpatiaLite (Fig. 1).

1. Base geodata

As with any GIS there was a need to obtain base cartography: ASTER-GDEM was used to create a DTM with a horizontal resolution of 30 m, limited to the island of Crete only. Based on this DTM with raw elevation data, we also created a “hillshade map” and a color-coded DTM that were eventually used as the main cartographic base at small scale visualisations. ASTER-GDEM is licensed from NASA-METI and free for non-commercial use only, downloaded upon registration, unlike the SRTM dataset. However, SRTM has a lower horizontal resolution than ASTER-GDEM.

For large scale visualisation, the KTEBASEMAP 2007–2009 (Ορθοφωτογραφίες για το σύνολο της Ελλάδας) provided high-resolution imagery via WMS, that proved very useful for identifying the exact location of extant archaeological remains on the ground in many cases. WMS is an OGC standard for raster data that is downloaded only for the needed geographic extent and at the desired scale. KTEBASEMAP is not downloadable, but it is available under the Creative Commons - Attribution 3.0 license.

OpenStreetMap was used to obtain data of the modern coastline of the island through the geofabrik.de download service. OpenStreetMap data is available under the Open Database License 1.0 and it is freely downloadable.

The *Archaeological sites* dataset of Digital Crete was used as a reference catalogue of archaeological sites known from previous literature, even though it is only web-based and no downloadable dataset is available.

2. Data model

Following the lead of other established databases of ancient places and archaeological sites (Digital Crete,

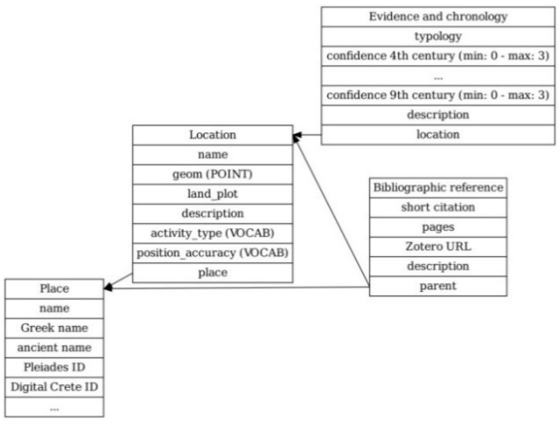

Figure 2 Simplified schema of the data model

Pleiades) we kept a clear separation between archaeological sites as "places" and the specific material evidence resulting from rescue and systematic excavations, field survey and other occasional findings. This assumption makes the database slightly more complex (Fig. 2) but also more flexible, particularly when incomplete or uncertain data need to be recorded. We had no need to define tables for vocabularies of terms (commonly used as drop-down menus) so far, but some fields are constrained to specific lists of values (geospatial accuracy, type of archaeological activity).

Unlike other GIS applications, the recording of spatial features is not the central focus of our data model: places can have more than one location attached, as is common in urban sites that span large areas. This one-to-many relationship is an advantage because on one hand, the data model allows to tie together different pieces of evidence that would be otherwise described as completely separate "sites", but on the other hand, there is no limit on the amount of detail that can be recorded for complex sites. When we need to analyse data at the scale of the entire island, each place is given point coordinates through the *ST_Centroid()* function that is part of the OGC-Simple Features Specification provided by SpatiaLite, by collating all locations linked to a place in a database view instead of a table. In SpatiaLite, views share the same *R*Tree* spatial index of parent tables and are as fast.

As described below in the «Collection of data» section, to keep track of varying degrees of confidence about chronology as given in archaeological reports, the chronology of each location is not recorded as a simple "from – to" time span, but accounts for the changing nature of settlements over time. This is based on the Evidence table, where one record per evidence type is stored. Standard database normalisation would require a nested design with at least two tables, but in this case we opted for a basic approach: there is one column per century (from the 4th to the 9th) and confidence values are recorded as integer values ranging from 0 (no evidence) to 3 (complete and clear evidence).

Finally, both places and locations accept simple bibliographic references to record the source of information. "Simple" means no attempt was made to create from scratch a complete bibliographic database, but only a short citation is provided and complete data are stored in Zotero, a web-based and publicly accessible reference management system. Zotero has an API to retrieve programmatically content from a set of URLs pointing to resources or collections of resources, so these will be stored in the database if need arises to have a complete and independent set of data.

3. Collection of data

Data were collected mainly through a systematic study of journals and other publications, and there are various types of information that need to be treated separately: geographic coordinates, chronology of occupation, settlement type and size, more detailed archaeological evidence, bibliographic references.

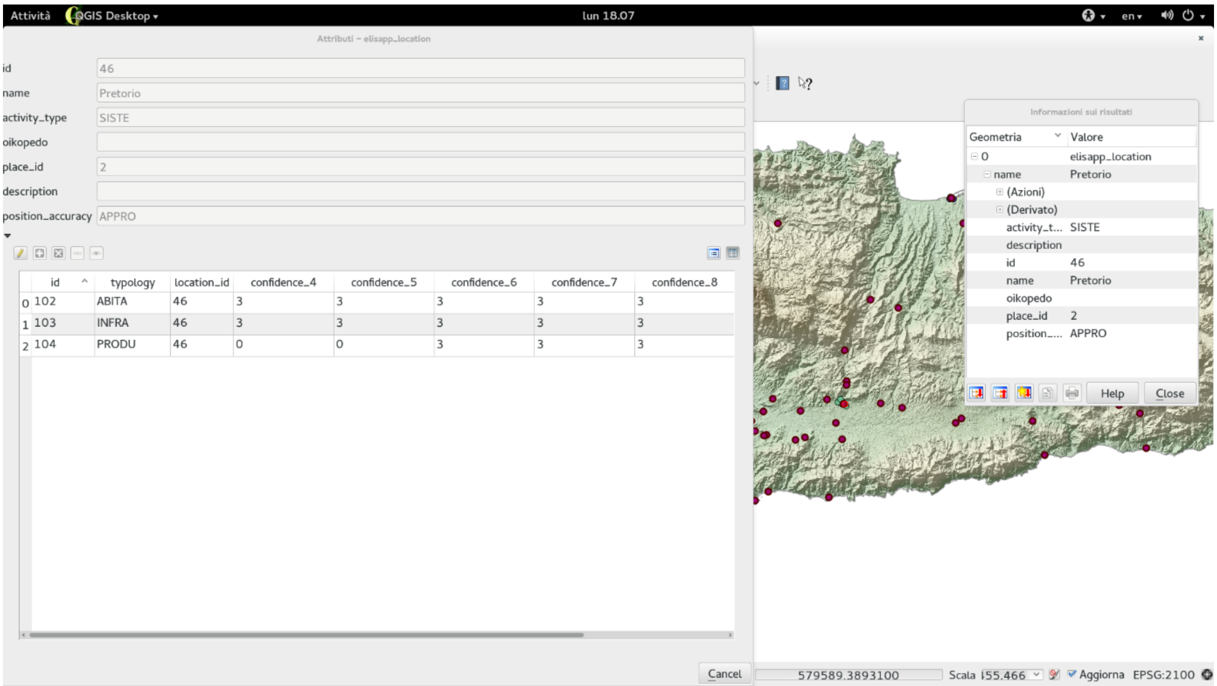

Figure 3 QGIS screenshot of the editing form for a "location" record (Pretorio in Gortyna). In the middle the sub-form showing "evidence" records.

As far as chronology is concerned, the main problem is without any doubt the wide range of differing terminology used in publications (as “late antique”, “late roman”, “early Christian”, “early byzantine”), often referred to the same period but rarely described in more detail. This is found most often in older reports and publications, and in some cases one may even question whether the provided chronology is acceptable by today’s standards and more refined typologies. Almost certainly, the underlying reason is to be found in the lack of interest for the Late Roman and Byzantine periods that was very common until a few decades ago in Cretan archaeology. Given this situation, we decided to record not only whether each excavation yielded evidence of occupation in a certain century among those considered, but also the degree of confidence in such chronology. Otherwise there would have been no distinction between recent and older data, nor between generic dates and precise ones – the “notes” field is notoriously used for free form annotations that are very difficult to parse in a database setting. When collecting data from separate sources it seems somehow necessary to assess the reliability of data, even in those cases when all datasets are of the same type (Gandini *et al.* 2008, 3-4), a condition which does not hold for our study.

Uncertainty extends to another type of data, geographic coordinates: in fact, some of them were surveyed directly on the ground with a GPS device, some other were identified on the basis of published topographic maps, but in some cases only raster imagery was used to obtain the position of archaeological sites. Furthermore, rescue excavations are almost always “positioned” with the indication of the land plot (*oikopedo*) that is not straightforward to pinpoint on a map. Older reports may indicate hotels or buildings that no longer exist; roads and village names only provide a generic reference. Therefore, the source and accuracy of geographic coordinates was recorded along with the actual data, both as a reminder that further work is needed for some records and also in case other researchers were to use our dataset in the future. Pleiades uses a similar approach.

Rather than trying to categorise a site according to a predefined typology (e.g. town, village, etc.), describing a type of “settlement” as a whole, the evidence table is made to record the low-level category of functional evidence: graves, production areas, residential areas, religious buildings, and infrastructure. An excavation or survey “site” can be associated with more than one of such categories, each with their own chronology as seen in the screenshot for the “Pretorio” in Gortyna (Fig. 3). This approach has the advantage of avoiding a bipolar scheme of “urban” versus “rural” sites, particularly for the period from the 7th century onwards for which it would be misleading (Veikou 2009).

Finally, keeping places and locations as separate objects in the database was useful for recording those pieces of evidence that are not precisely located (e.g. finds that were moved long ago to a museum) but still need to be recorded.

4. GIS environment and tools

We created a GIS working environment using QGIS (versions 2.0 and 2.2), a well-known open source GIS package that is widely used in archaeology. QGIS enabled us to take advantage of the underlying

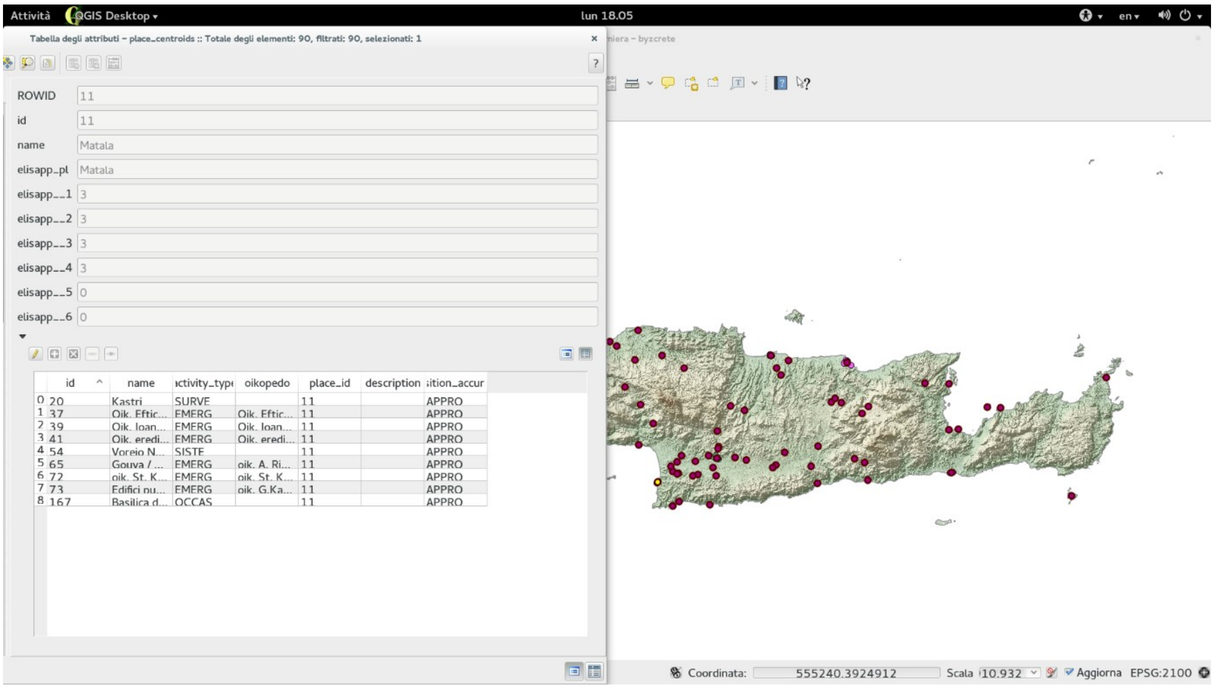

Figure 4 QGIS screenshot of the editing form for “place” (Matala). On the left the sub-form with “locations”.

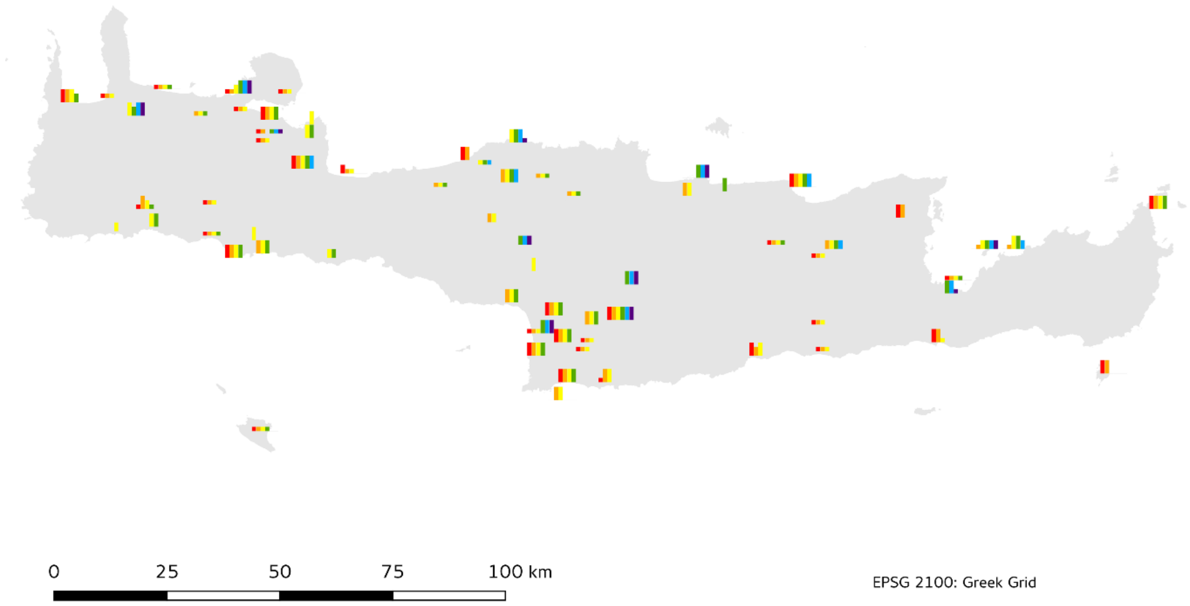

Figure 5 Map with diagram overlays at recorded sites. Bar charts represent chronology and confidence. Each color bar corresponds to one century: 4th (red), 5th (orange), 6th (yellow), 7th (green) 8th (blue), 9th (purple).

capabilities of SpatiaLite (version 3.1 and 4.1). SpatiaLite is a truly relational database, unlike the popular Shapefile, but retaining much of its simplicity because it is file-based and no client-server setup is needed. The relational database schema we created is based on standard practice, with one-to-many relations between tables (place, location, evidence, bibliographic reference) and foreign key constraints. Only one of the database tables contains spatial data (location), but QGIS can load both spatial and non-spatial tables from various data sources, including SpatiaLite and SQLite databases. Joins and foreign key relations between tables/layers are managed from the properties of each layer, without need for third-party plugins. The recently released 2.2 version has an automatic form generator that creates "sub-forms" directly within the editing window (as shown in the screenshots, Fig. 3 and 4).

Other features of QGIS that we used include various styling and labelling tools based on data attributes, and more advanced mapping techniques such as reprojection and diagram overlays. Map reprojection was necessary due to the diversity of base data, some in geographic reference systems (EPSG 4326), some in cartographic reference systems (EPSG 2100 – Greek Grid). The point data in our database is stored as geographic coordinates in EPSG 4326 (WGS 84) but maps are made using the EPSG 2100 projection. Reprojection of vector data is made in QGIS.

Diagram overlays are a data visualisation technique where diagrams (typically bar charts or the less useful pie charts) are associated with each point on the map. In our case, only the subset of sites for which the collecting of data is already completed is shown (Fig. 5). Diagrams are based on the "chronology and confidence" data, where each bar corresponds to one century. While this map is more cluttered than a set of simpler maps, each containing only sites that were occupied during one century, we found it useful because colors provide a general overview that is otherwise difficult to obtain.

5. Data analysis

Based on this preliminary work and the ongoing collection of data, we found QGIS together with SpatiaLite capable of acting as a complete platform to record data and also as a testbed of interpretative models – a task that we are still pursuing at this time. Models under study are those typically associated with the study of settlement patterns: walking distance, inter-site visibility, relationship with sea and land communication networks. One such example is shown in the bar chart (Fig. 6), with the average site distance from the coast, by century. In the later period coastal sites become less widespread: by observing the general changes in the Mediterranean at this time, the Byzantine Empire is seen shrinking to the Aegean area and the central Mediterranean, while Africa, Egypt and the Levant come under Arab rule. The development seen in fig. 6 is therefore significant to understand this general phenomenon, even though only a preliminary appraisal is possible at the time of this writing.

These models can be defined with regard to the database as SQL queries of varying complexity, but the basic idea is that these queries can be run directly on the raw data. The barchart shown in Fig. 6 is based on a spatial query using the *ST_Distance()* and

ST_Collect() functions. *ST_Collect()* creates a single geometry collection from all its arguments, in our case all the LINESTRING objects that make the coastline of Crete (with many small islands), loaded into the database. *ST_Distance()* returns the minimum distance between two geometric entities: in this case, the coastline and each point representing a site. This same procedure can be run for any other analysis based on vector data. Other methods are available directly from QGIS, such as sampling of raster layers (e.g. to obtain average elevation at a site from a DTM).

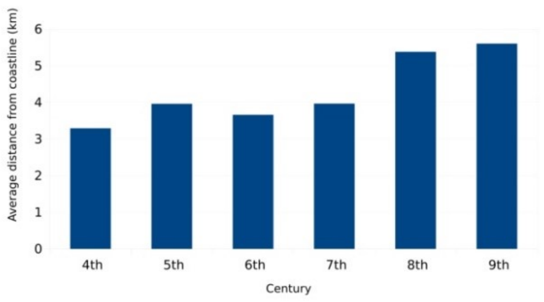

Figure 6 Average distance of sites from coastline, by century, in kilometers. In the later period coastal sites became more rare.

Conclusions

The combination of QGIS and SpatiaLite allowed us to develop a complete GIS environment, capable of recording data according to the needs of the main research project, including geospatial data. A layered data model was necessary in order to avoid assigning arbitrary values to old data from published literature and such a model was created and successfully managed in the same GIS environment. Data are archived in a SpatiaLite database file, that is both easily shared and in open format, compatible with any GIS software. Finally, based on the current state of the collected data, various exploratory analysis techniques were used to gain a better understanding of the changes occurring in Cretan landscapes during the period from the 4th to the 9th century.

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3D PSEUDO GPR SECTIONS BASED ON NORMALIZED DIFFERENCE VEGETATION INDEX VALUES: FUSION OF OPTICAL AND ACTIVE REMOTE SENSING TECHNIQUES AT THE VÉSZTO-MÁGOR TELL, HUNGARY

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Περίληψη/ Abstract

Η χρήση τηλεπισκόπησης με οπτικούς ή παθητικούς δέκτες έχει ευρέως διαδοθεί για τον εντοπισμό υπεδάφιων αρχαιολογικών καταλοίπων. Όμως η συνδυασμένη χρήση επίγειων φασματοραδιομέτρων, υψηλής χωρικής ανάλυσης δορυφορικών δεδομένων αλλά και επίγειων δεδομένων ραντάρ στην αρχαιολογική έρευνα είναι ακόμη αρκετά περιορισμένη. Επίγειες μετρήσεις από φασματοραδιόμετρα και δεδομένα ραντάρ (GPR) έχουν παρθεί από τη θέση Vészto-Mágor Tell, που βρίσκεται στο νοτιοανατολικό άκρο της Ουγγαρίας. Οι υπερφασματικές μετρήσεις ανακλαστικότητας από το φασματοραδιόμετρο έχουν προσομοιωθεί στο δορυφόρο GeoEye-1 και ακολούθως υπολογίστηκε ο δείκτης NDVI. Τόσο ο δείκτης αυτός όσο και τα αποτελέσματα από τα GPR έχουν χωριστεί σε 10 κλάσεις με σκοπό να μειωθεί ο υπολογιστικός φόρτος. Στη συνέχεια, με βάση αυτά τα δεδομένα δημιουργήθηκε ο πίνακας πιθανοτήτων με βάση ένα μικρό δείγμα από την κοινή περιοχή μελέτης. Με αυτόν τον τρόπο για κάθε βάθος (20 cm), για τομή από 0–2 m εχει υπολογιστεί η πιθανότητα $P_{(GPRi \mid NDVIi)}$. Ο πίνακας πιθανοτήτων προβλήθηκε στη συνέχεια στη δορυφορική εικόνα GeoEye-1. Τα αποτελέσματα δείχνουν ότι το τρισδιάστατο ψεύδο GPR αποτέλεσμα είναι σε θέση να ταυτιστεί με τις επίγειες γεωφυσικές διασκοπήσεις όπως επίσης και να χρησιμοποιηθεί για να εντοπίσει νέες περιοχές με αρχαιολογικό ενδιαφέρον στην περιοχή.

Optical and active remote sensing techniques have been widely used for the detection of buried archaeological remains. However the integration of ground spectroscopy, high resolution multispectral imagery and ground penetrating radar (GPR) is still very limited. In this paper an attempt to integrate the above mentioned techniques is presented. Ground spectroradiometric and GPR measurements have been simultaneously collected at the Vészto-Mágor Tell, located in the southeastern part of Hungary. The narrowband reflectance values of the spectroradiometer have been resampled to simulate the GeoEye-1 satellite, and then the Normalized Difference Vegetation Index (NDVI) was calculated. Both NDVI and GPR depth slices (depth interval 20cm) were classified into 10 classes in order to reduce the computational time. Therefore for each depth (20cm) from 0–2m below surface, the probability $P_{(GPRi \mid NDVIi)}$ was estimated. This probability aims to predict and map the presence of GPR anomalies (e.g. archaeological underground targets) based on the a-priory knowledge of the NDVI index. This probability matrix was then projected to a high resolution satellite image (GeoEye-1). The results have shown that the 3D pseudo GPR sections as retrieved from the GeoEye-1 image were able to verify the in situ geophysical prospections as well as to identify potential future GPR measurements in other areas of the tell.

Keywords: 3D pseudo GPR section, fusion, ground spectroscopy, probability matrix.

Introduction

In the last years high resolution satellite images have been systematically used for the support of archaeological research (Laet *et al.* 2007). Many researchers have been able to exploit the visible and near infrared part of the spectrum in order to detect possible archaeological marks in satellite images (Masini & Lasaponara 2007, Cavalli *et al.* 2007). Ground spectroradiometric measurements have been suggested as an additional way for supporting satellite analysis results or for ground truthing crop marks (Agapiou *et al.* 2010, 2012). In the verification of the suggested features observed in satellite images, geophysical measurements, including ground penetrating radar (GPR) are able to provide 3D information about these relics (Cardarelli & Filippo, 2009, Papadopoulos *et al.* 2010, Sarris *et al.* 2012).

Although remote sensing prospection techniques are able to provide valuable information, these practices have their limitations. Geophysical surveys can provide 3D data at different levels but their spatial extent is rather limited compared to a satellite image. In contrast, satellite images along with ground spectroradiometric measurement are able to provide only 2D information of the surface. Accurate spectral profiles are able to be collected using the ground spectroradiometers while satellite data may suffer from atmospheric effects.

In this paper an attempt is made in order to provide 3D pseudo GPR sections over large areas in the Vészto-Mágor Tell by integrating the previous mentioned techniques. The paper is organized as followes: at first a brief description of the case study area is given. Then the methodology followed is explained. The paper ends with the preliminary results of this study.

The main idea of the methodology followed in this paper is to create a probability matrix between ground measurements and then apply these probabilities to satellite images.

1. Case study area

Vészto-Mágor Tell (Fig. 1) is located on the southeastern Great Hungarian Plain (Békés County) in a meander loop of the Holt-Sebes-Körös River. The Tell is composed of cultural and natural layers rising to a height of about 9 m above mean sea level. Systematic archaeological investigations of the site began in 1968. The site became one of the Hungarian National Parks in the 1980s. Currently, in addition to the archaeological museum located within a historic wine cellar, the 1986 excavation trench is also visible where a number of features from different periods remain *in situ* (Sarris *et al.* 2012)

Figure 1 Photograph taken from the Vészto-Mágor Tell during the field campaigns.

2. Methodology

In situ spectroradiometric measurements where collected at the northern part of the tell (see Fig. 2, red polygon) using the GER 1500 spectroradiometer. This instrument has the capability to record the electromagnetic radiation from 350–1050 nm with 1.5nm interval. The measurements were taken every 1 m along S-N transects which were spaced 2 m apart in W-E direction. An area of 2600m^2 (100m x 26m) was surveyed with the ground spectro-radiometer. In total more than 1200 measurements were collected. In addition, magnetic (Bartington G601 fluxgate gradiometer), EM (GEM-2 Geophex) and GPR (Noggin Plus of Sensors&Software with antennas of 250MHz) measurements have been collected in a broader area (see Fig. 2). Sampling was every 1m with 5 different frequencies (5010, 10050, 20010, 30030, 40050 Hz) for the EM measurements, 0.5m for the magnetic measurements and 0.25m along parallel transects of 0.5m aparrt for the GPR. Processing of the geophysical data included the creation of mosaics, grid and line equalization techniques, compression of dynamic range and the application of directional filters. Processing of the GPR transects was carried out by first selecting the first peak signal for each transect and then applying AGC, Dewow and DCshift filters aiming to the enhancement of the reflected signals. (see Sarris *et al.* 2012).

Figure 2 Left: Entire area of the Vészto-Mágor Tell covered from the different remote sensing techniques; Grey and blue polygons indicate the area covered from the geophysical surveys (GPR and magnetic respectively) while red polygon indicates the area covered from ground spectroradiometer. The whole area of the Tell was also captured from satellite images (not indicated with polygon). Right: Detail map from the common area covered from all remote sensing techniques (geophysical; satellite image; ground spectroradiometric measurements) (background Google Earth) (Sarris *et al.* 2012).

The in-situ spectroradiometric measurements were then recalculated based on the Relative Response Filters of the GeoEye-1 sensor. Then the NDVI index was retrieved. Both NDVI values and GPR (20cm interval depth) were then classified into 10 classes in order to minimize the computational time.

A relationship matrix between NDVI and GPR classes was defined in the common area using probability statistics. Therefore, for each NDVI class the probability $P_{(GPRi\ |NDVIi)}$ was estimated. These probability values were then applied to the satellite image (i.e. NDVI of GeoEye-1).

3. Results

Based on the above methodology, the results from the five steps followed are presented below:

3.a Step 1: Spectral convolution of the in-situ spectroradiometric measurements based on the Relative Response Filters of the GeoEye-1 sensor.

A handheld GER-1500 field spectro-radiometer was used, in order to retrieve the spectral signatures of the vegetation (low grass) in the area. Reflectance (see Fig. 3) was calculated as a ratio of the target radiance to the reference radiance. The target radiance value is the measured value taken on the surface of the vegetation; and the reference radiance value is the measured value taken on the standard Spectralon panel, representing the sun radiance, which reaches the earth surface without atmospheric influence. As it is shown in Fig. 3 reflectance differences can be observed over the vegetation of the area, especially in the VNIR part of the spectrum (720–900 nm).

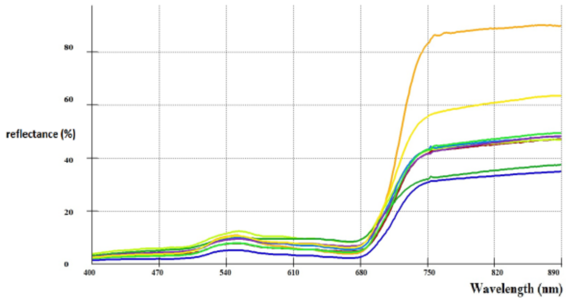

Figure 3 Typical spectral signatures taken with the ground spectroradiometer in the Vészto-Mágor Tell.

Using the Relative Response Filters of the GeoEye-1 sensor (Fig. 4) the above narrow band reflectance values were used in order to calculate the broadband reflectance values of vegetation (i.e. Bands 1–4 of the GeoEye-1 sensor). Therefore the point samples from the spectroradiometric campaign can be interpolated to a continue surface–image using the Inverse Distance Weighted (IDW) algorithm (Fig. 5).

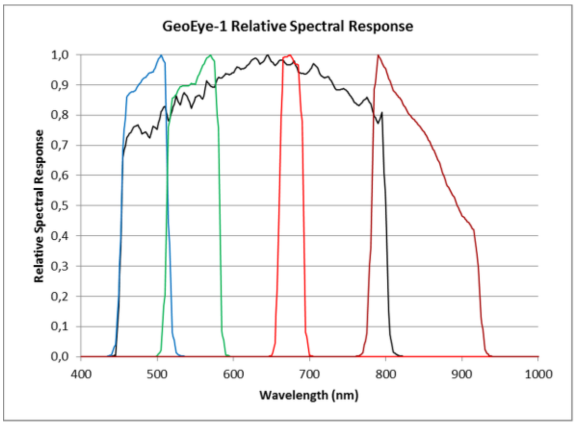

Figure 4 Relative Response Filters of the GeoEye-1 sensor.

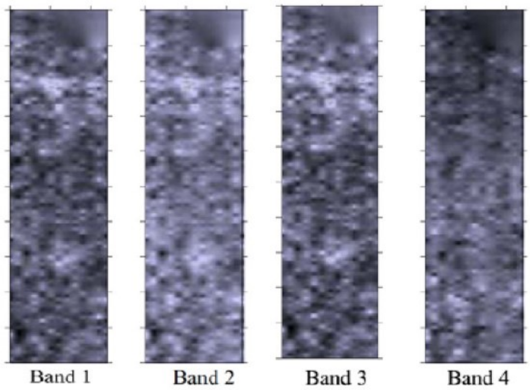

Figure 5 Visible and Near Infrared bands, of the GeoEye-1 sensor, as derived from the ground spectroradiometric campaign.

3.b Step 2: Calculation of the NDVI index and GPR sections.

Both red and NIR bands of Step 1 were used in order to calculate the NDVI index in the Vészto-Mágor Tell area using equation 1:

$$NDVI = (p_{NIR}-p_{red}) / (p_{NIR}+p_{red}) \qquad [eg. 1]$$

Where:

p_{NIR} = reflectance of the NIR band
p_{red} = reflectance of the red band

The value of the NDVI index ranges between -1 to +1. A 2D as well as a 3D presentation of the results are show in Fig. 6.

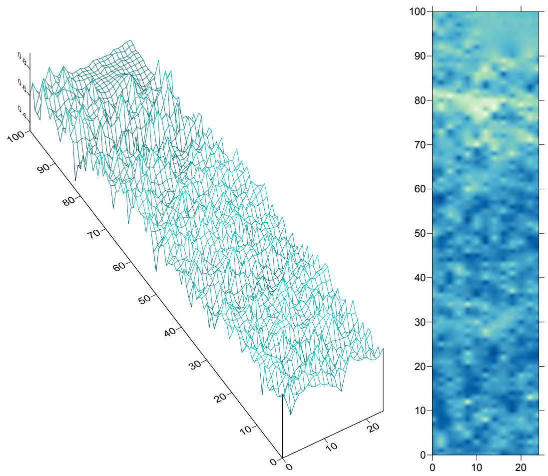

Figure 6 2D and 3D view of the NDVI index.

Finally, horizontal depth slices from the GPR measurements at different depth levels were created from the original vertical sections assuming a velocity for the electromagnetic waves equal to 0.09 m/ns (estimated through hyperbola matching techniques) (Fig. 7).

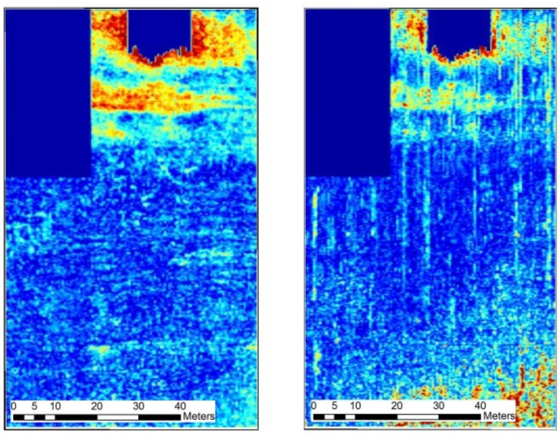

Figure 7 GPR depth slices at different depth levels

3.c Step 3: Probability matrix P(GPRi │NDVIi)

From the common area of the GPR and the spectroradiometric measurements (see Fig. 2, red square) the probability matrix P(GPRi │NDVIi) was estimated. For computational reasons the NDVI image (Fig. 6) was classified to 10 classes using the K-means classifier. The k-means clustering aims to partition n observations into k clusters in which each observation belongs to the cluster with the nearest mean. The same procedure was also applied for the GPR sections. Therefore each NDVI class has a different probability to "match" with the different GPR classes and for the different depths. The total probability combinations are consequently 10 x 10 x 10 = 1000 (10 NDVI classes; 10 GPR classes; 10 different depth levels 0–2 meters, 0.20m interval).

An example of the probability matrix P(GPRi │NDVIi) for the depth level 0–0.20m is shown in Table 1.

NDVI	GPR measurements								
	Low									High
Low	.02	.02	.01	.02	.01	.02	.03	.10	.24	.52
	.01	.03	.04	.05	.07	.09	.12	.20	.19	.20
	.02	.07	.10	.10	.09	.08	.10	.17	.16	.10
	.01	.08	.11	.16	.12	.08	.13	.10	.13	.08
	.03	.10	.17	.19	.15	.08	.12	.07	.06	.04
	.05	.15	.19	.18	.13	.11	.08	.04	.04	.03
	.08	.18	.23	.19	.12	.07	.06	.02	.02	.02
	.06	.21	.22	.19	.13	.09	.06	.01	.01	.01
	.08	.22	.24	.19	.12	.07	.04	.02	.01	.00
High	.10	.24	.23	.16	.11	.07	.05	.02	.01	.01

Table 1 Probability matrix of NDVI and GPR values for a depth 0–0.20 cm below surface.

Fig. 8 (right) shows an example of a probability P(GPRi │NDVIi) image for the 40–60cm depth. The already excavated site at the Tell was excluded from this analysis (see Fig. 8, left) since the algorithm is valid only in vegetated areas.

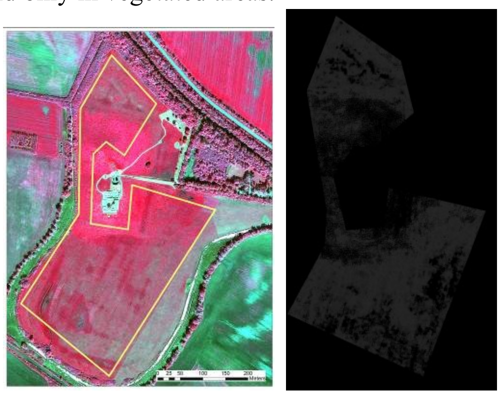

Figure 8 Example of probabilities P(GPRi │NDVIi) for 40–60cm depth level. White values indicate high probability while black values low probability (right). The area examined in this study indicated with yellow colour (left).

3.d Step 4: Application of P(GPRi │NDVIi) to the GeoEye-1 satellite image.

In the final step, the GeoEye-1 image was used. Initially the NDVI index was calculated again for the satellite image and then a classification was made using the k-means algorithm. The 10 new classes for the NDVI values in the satellite image are shown in Fig. 9.

It should be noticed that the GeoEye-1 image had an overpass after a few days from the field campaigns.

Therefore similar classes are expected both in the satellite image as well in the spectroradiometric campaign.

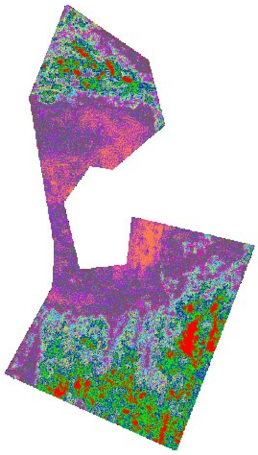

Figure 9 The NDVI GeoEye-1 image after the k-means classification (10 classes).

Finally, the probability matrix from step 3 was applied to the NDVI GeoEye-1 image. Hence ten 3D pseudo GPR depth slices where created from 0.0–2.0m depth below surface using a 20cm depth interval. Each of these images corresponds to the possibility to detect GPR anomalies at a specific depth. Fig. 10 (left) shows the common area where the real GPR measurements have been carried out while Fig. 10 (right) displays the corresponding pseudo GPR results. Differences between real and pseudo images are expected since the 3D pseudo information is retrieved from the 2D NDVI data.

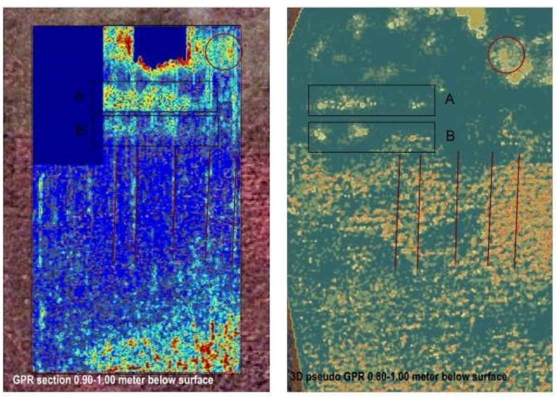

Figure 10 Left: GPR section of 0.90-1.00 meter as recorded from the geophysical survey. Right: 3D pseudo GPR section at a depth of 0.80–1.00 meter below surface.

However, the benefit of this approach is the fact that the pseudo GPR image can be further expanded to the entire area of the archaeological site. For instance Fig. 11, shows the results from the pseudo GPR section of 60–80cm below surface (right), based on the NDVI values of the GeoEye-1 image (left). As it is presented further to the areas which have been measured with geophysical instruments other sections of the site to the south are also promising.

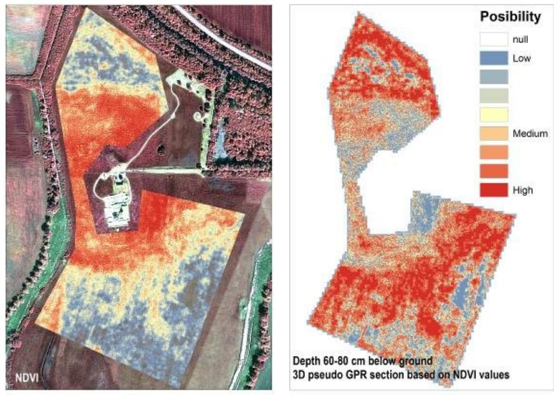

Figure 11 Left: NDVI profile of the GeoEye-1 image. Right: 3D pseudo GPR section at a depth of 60–80 cm below surface.

Using the different 'layers' of information a 3D model can be created. As it is shown in Fig. 12 the 3D model can be interpreted by the experts in the same way as the GPR 3D models. This approach gives a new perspective to the researchers dealing with the detection of buried archaeological remains. In addition, in Fig. 12 details from the 3D pseudo GPR model and from the GPR section tend to give similar results.

This highlights the benefits from the abovementioned methodology proposed: using satellite images a 3D pseudo GPR model can be applied to detect some promising targets in extended areas. These targets can be then examined using ground techniques (e.g. GPR), while the results can be integrated again back to the methodology for a new probability matrix.

Conclusions

This paper aims to integrate different remote sensing techniques, both optical and passive in order to exploit further their capabilities. 3D pseudo GPR depth slices were able to be mapped based only on NDVI images. These values were initially calculated on ground spectral signatures and geophysical campaigns.

The proposed methodology can be used as a first step to detect high priority areas for GPR measurements, while near real-time GPR measurements can be incorporated into the possibility matrix in order to improve the final GPR pseudo images.

Several vegetation indices can be further examined – in contrast to the NDVI index presented here – or more complex algorithms can be evaluated during the development of the probability matrix.

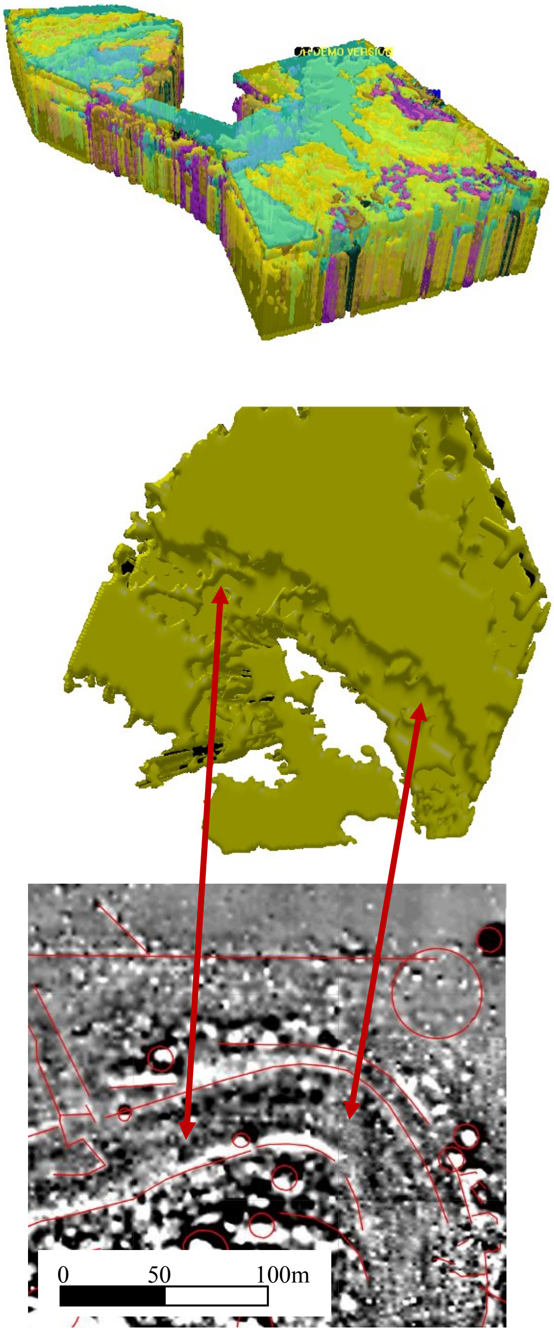

Figure 12 Above: 3D model of the pseudo GPR product. Below: Detail of the 3D model and comparison with the magnetic results. The section of the magnetic map covers 120x120 square meter towards the north of the tell.

Acknowledgments

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ΔΙΑΧΕΙΡΙΣΗ ΑΡΧΑΙΟΛΟΓΙΚΩΝ ΔΕΔΟΜΕΝΩΝ ΜΕ ΤΗ ΧΡΗΣΗ ΓΕΩΓΡΑΦΙΚΟΥ ΣΥΣΤΗΜΑΤΟΣ ΠΛΗΡΟΦΟΡΙΩΝ Η ΠΕΡΙΠΤΩΣΗ ΤΟΥ ΠΗΛΙΟΥ

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Περίληψη/ Abstract

Η πολυπλοκότητα και το πλήθος των πληροφοριών που απαιτούνται ή παράγονται καθημερινά στις αρχαιολογικές δραστηριότητες μίας Εφορείας Αρχαιοτήτων οδήγησε στην πιλοτική εφαρμογή ενός προγράμματος συγκέντρωσης και επεξεργασίας τους μέσω της τεχνολογίας G.I.S., με πεδίο εφαρμογής την περιοχή του Πηλίου. Πραγματοποιήθηκε η ψηφιοποίηση των χαρτών που χρησιμοποιούνται ως υπόβαθρο, σχεδιάστηκε μια απλή και εύχρηστη βάση δεδομένων με διοικητικά, γεωγραφικά, αρχαιολογικά και τοπογραφικά δεδομένα και συνδυάστηκαν όλα τα παραπάνω σε μία εφαρμογή G.I.S. με γνώμονα την απλότητα της χρήσης και την αμεσότητα της πληροφορίας. Πρόκειται για μια εφαρμογή που μπορεί να χρησιμοποιηθεί τόσο στο γραφείο για πιο πολύπλοκες και απαιτητικές εργασίες, όσο και στο πεδίο. Στην ανακοίνωση τοίχου παρουσιάστηκαν τα παραπάνω και τα μέχρι σήμερα αποτελέσματα με πραγματικά δεδομένα και σε πραγματικές συνθήκες εργασίας, από την περιοχή του Πηλίου.

The complexity of information produced daily during the archaeological activities at an Ephorate of Antiquities led to the development of a GIS project for collecting and processing data, focusing on the area of Pelion. The operation, the benefits and the limitations of such a system are described in the paper. The specific application is deliberately simple in order to be easy to use by anyone at the office and the field. It keeps archaeological and administrative information related to the area of Pelion, produced by the everyday archaeological activity and processing of the data.

Λέξεις Κλειδιά: Πήλιο, Μαγνησία, ΙΓ’ ΕΠΚΑ, G.P.S., G.I.S.

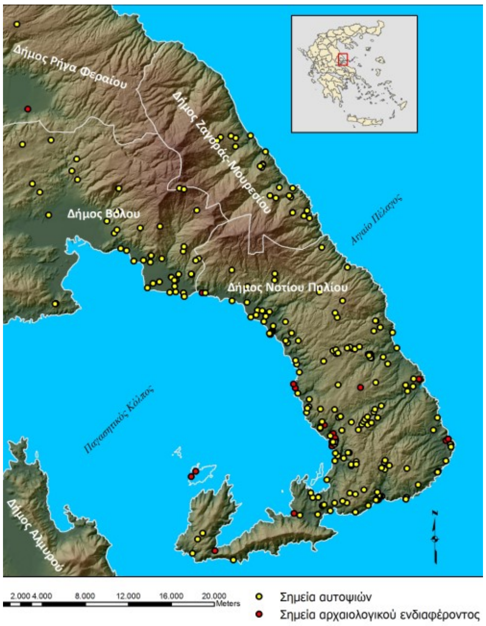
Εισαγωγή

Το όρος Πήλιο με υψόμετρο 1624 μ., βρίσκεται στο ανατολικό άκρο της Μαγνησίας και βρέχεται από τρεις πλευρές (ανατολή, δύση και νότο) από θάλασσα, τον Παγασητικό κόλπο και το Αιγαίο πέλαγος. Γεωλογικά αποτελείται κυρίως από σχιστόλιθο και εν μέρει από ασβεστόλιθο. Η βλάστηση παρουσιάζει αξιοσημείωτη βιοποικιλότητα από περιοχές με θαμνώνες μέχρι δασώδεις εκτάσεις κυρίως καστανιάς και δρυός. Το κλίμα παρουσιάζει έντονες διακυμάνσεις τόσο μεταξύ διαφορετικών εποχών όσο και μεταξύ παράλιων και ορεινών περιοχών.

1. Το ιστορικό και το πλαίσιο των αρχαιολογικών ερευνών στο Πήλιο

Οι οργανωμένες αρχαιολογικές έρευνες στο Πήλιο ξεκίνησαν στις αρχές του 20^{ου} αιώνα (Wace 1906, Αρβανιτόπουλος 1906) και συνεχίζονται μέχρι σήμερα (Αδρύμη 1992, 1993, 2001, Βουζαξάκης υπό έκδοση α, β, γ, Marzolff 2006, Ιντζεσίλογλου 2010). Ωστόσο, αποδείχθηκαν δύσκολες διαχρονικά, λόγω κυρίως του δύσβατου της περιοχής, των μεγάλων αποστάσεων μεταξύ των διαφόρων περιοχών αλλά και από το αστικό κέντρο του Βόλου, όπου βρίσκεται ανέκαθεν η έδρα της Εφορείας Αρχαιοτήτων (ΙΓ' Ε.Π.Κ.Α.), του δύσκολου οδικού δικτύου και των ακραίων καιρικών συνθηκών κυρίως στη διάρκεια του χειμώνα.

Στον ορεινό όγκο του Πηλίου περιλαμβάνεται ένας μεγάλος αριθμός χωριών και άλλων μικρότερων οικισμών, γεγονός που συνεπάγεται μία σχετικά έντονη οικοδομική δραστηριότητα, ταυτόχρονα με την εκτέλεση δημόσιων έργων κοινής ωφελείας (π.χ. οδικά δίκτυα, δίκτυα ύδρευσης) και την πραγματοποίηση ποικίλων οικονομικών δραστηριοτήτων (αγροκτηνοτροφικές μονάδες, λατομεία, κεραίες κινητής τηλεφωνίας κ.λ.π.). Αυτό συνεπάγεται μια σειρά αιτήσεων στην αρμόδια αρχαιολογική υπηρεσία (ΙΓ' ΕΠΚΑ) για έγκριση εκτέλεσης έργων από πλευράς της αρχαιολογικής νομοθεσίας (Εικ. 1). Η τυπική διαδικασία αρχαιολογικού ελέγχου περιλαμβάνει την εξέταση τοπογραφικών διαγραμμάτων και τους χαρτών, την προσπάθεια συσχετισμού της συγκεκριμένης θέσης με κηρυγμένους ή άλλους γνωστούς αρχαιολογικούς χώρους, την αναζήτηση γνωστών πληροφοριών για την περιοχή από τη βιβλιογραφία και την έρευνα στο αρχείο εγγράφων για ανεύρεση ανάλογων υποθέσεων που σχετίζονται με την περιοχή ενδιαφέροντος, προκειμένου να ακολουθήσει η διαδικασία της αυτοψίας και της επιτόπιας έρευνας.



Εικόνα 1 Χάρτης Πηλίου με ψηφιακό μοντέλο εδάφους (DEM) και σημειωμένα όλα τα σημεία αρχαιολογικού ελέγχου της τελευταίας τετραετίας (±400).

1α. Τα προβλήματα της έρευνας

Ωστόσο, ο εντοπισμός πολλών αρχαιολογικών χώρων από παλαιότερες αρχαιολογικές έρευνες, παραμένει ακόμα και σήμερα αρκετά προβληματικός λόγω ελλιπών στοιχείων τεκμηρίωσης. Χαρακτηριστικό παράδειγμα αποτελούν οι ανασκαφικές έρευνες του Αποστόλου Αρβανιτόπουλου στην περιοχή της Κορόπης (Αρβανιτόπουλος 1906, 123 και 1907, 175) και στα Χάνια (Αρβανιτόπουλος 1911, 305) στις αρχές του 20ου αιώνα, όπου αποκαλύφθηκαν δύο σημαντικά ιερά της αρχαίας Μαγνησίας, του Κοροπαίου Απόλλωνος και του Ακραίου Διός αντίστοιχα. Άλλοτε πάλι, αινιγματικές είναι και ορισμένες κηρύξεις αρχαιολογικών χώρων παλαιότερων ετών, στις οποίες δεν συμπεριλαμβάνονταν αποσπάσματα χαρτών ή συντεταγμένες και έτσι ο εντοπισμός των χώρων αυτών δεν είχε επιτευχθεί μέχρι και σήμερα, όπως για παράδειγμα το Εβραιόκαστρο κοντά στον οικισμό του Αγίου Δημητρίου (Wace 1906, 152, Λιάπης 2010, 13–1143) ή τα σπήλαια του Σαρακηνού (Θεοχάρης 1967, 50–51) και του Αγίου Βλασίου (Υ.Α. 21220/10-8-1967, ΦΕΚ 527/Β/24-8-1967). Τέλος, ανεξιχνίαστες παρέμεναν και οι περιπτώσεις απλών αναφορών για την ύπαρξη αρχαιοτήτων σε περιοχές του Πηλίου από παλαιότερους συναδέλφους ή ακόμη και από πολίτες, όπως για παράδειγμα οι θολωτοί τάφοι στη «Λέσχιανη» (Αρβανιτόπουλος 1911, 292–294) ή τα προϊστορικά εργαλεία από τη «Χονδρή Άμμο» (Βουζαξάκης υπό έκδοση δ).

1β. Η αναδιοργάνωση της έρευνας

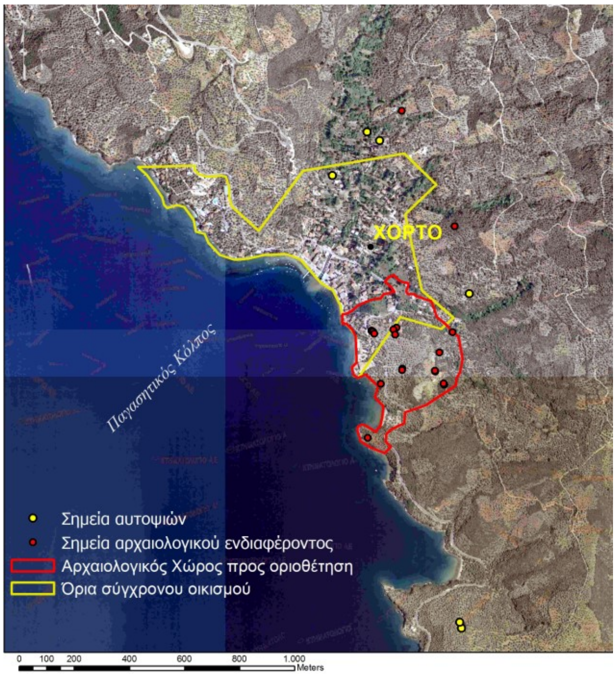
Από το 2006, ξεκίνησε μια συστηματική προσπάθεια ηλεκτρονικής καταγραφής όλων των αρχαιολογικών πληροφοριών, ταυτόχρονα με την καταγραφή και μελέτη των αρχαιολογικών ευρημάτων, που έχουν προκύψει από την μακρόχρονη έρευνα της περιοχής (Βουζαξάκης υπό έκδοση δ). Σχεδόν αμέσως κρίθηκε απαραίτητη η ανάπτυξη ενός συστήματος ηλεκτρονικής καταγραφής και τεκμηρίωσης των πολυάριθμων αρχαιολογικών αυτοψιών και περιοδειών σε αγροτεμάχια και περιοχές του Πηλίου, προκειμένου οι πληροφορίες που προέκυπταν κάθε φορά να μην χάνονται με την πάροδο του χρόνου και την εναλλαγή των ερευνητών και επίσης να καθίστανται ανά πάσα στιγμή εύκολα προσβάσιμες και αξιοποιήσιμες.

Έτσι, σε πρώτο επίπεδο έγινε μία εντατική προσπάθεια συγκέντρωσης και αρχειοθέτησης όλων των διάσπαρτων αρχαιολογικών πληροφοριών και δεδομένων από το παρελθόν με ταυτόχρονη απόπειρα εντοπισμού και ανάκτησης όλων των αρχαιολογικών χώρων-«φαντασμάτων», που είχαν υποπέσει σε ανυποληψία και είχαν πληγεί κυρίως από τη λήθη στο πέρασμα των χρόνων. Παρ' όλες τις προσπάθειες όμως, τα προβλήματα δεν ξεπεράστηκαν εύκολα. Ο εντοπισμός των θέσεων και ο συσχετισμός με τους αρχαιολογικούς χώρους εξακολουθούσε να αποτελεί μία διαδικασία χρονοβόρα, δυσλειτουργική, επισφαλή και πολλές φορές αναποτελεσματική. Και αυτό γιατί οι πληροφορίες αντλούνταν κυρίως από αποσπάσματα χαρτών, τοπογραφικά διαγράμματα και οδοιπορικά σκαριφήματα, που πολλές φορές είτε δεν περιείχαν καθόλου συντεταγμένες είτε ανέφεραν συντεταγμένες από διαφορετικά πολλές φορές μη εξαρτημένα συστήματα αναφοράς. Με τη βοήθεια τουριστικών χαρτών, οι οποίοι ήταν πιο εύχρηστοι στο πεδίο, γινόταν προσπάθεια εντοπισμού των θέσεων, ωστόσο λόγω του δύσβατου της περιοχής η προσπάθεια αυτή απέβαινε και πάλι πολλές φορές άκαρπη.

Κάποιες φορές προηγούνταν συνεννόηση με τον ιδιώτη για την υπόδειξη της θέσης, ο οποίος όμως δεν ήταν πάντα διαθέσιμος, με συνέπεια την αδυναμία προγραμματισμού πολλών αυτοψιών την ίδια μέρα και την καθυστέρηση στην διεκπεραίωση των υποθέσεων. Επιπλέον η έλλειψη ηλεκτρονικής αρχειοθέτησης των υποθέσεων και ηλεκτρονικής χαρτογράφησης των αυτοψιών καθιστούσαν ιδιαίτερα δυσχερή το συσχετισμό υποθέσεων από την ίδια περιοχή, με αποτέλεσμα τη διεξαγωγή επανειλημμένων επιτόπιων ερευνών σε θέσεις που είχαν ήδη ελεγχθεί κατά το παρελθόν.

1γ. Η μέθοδος

Με βάση και αφορμή τα παραπάνω αποφασίστηκε να εφαρμοστεί ένας πιο ευέλικτος τρόπος προσέγγισης της καθημερινής αρχαιολογικής εργασίας στο γραφείο και στο πεδίο και ταυτόχρονα να δημιουργηθεί μια απλή και λειτουργική βάση δεδομένων με όλα τα στοιχεία αυτής της εργασίας, η οποία πάνω από όλα θα μπορεί να παραμείνει χρήσιμη και κατανοητή και στο απώτερο μέλλον. Στραφήκαμε λοιπόν, στην διαρκώς εξελισσόμενη ψηφιακή τεχνολογία, η οποία τα τελευταία χρόνια έχει προσφέρει αρκετά προσιτές οικονομικά και τεχνικά λύσεις στο μέσο χρήστη, ενώ παράλληλα υπόσχεται ολοένα και μεγαλύτερες δυνατότητες. Κύριο μέλημά υπήρξε η επιλογή εφαρμογών που είναι διαδεδομένες, προσιτές και που να μπορεί να τις χρησιμοποιήσει εύκολα ένας μη ειδικός χρήστης.



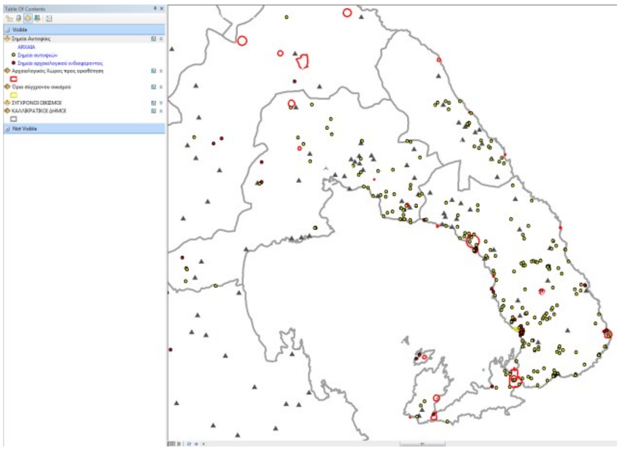
Εικόνα 1 Πήλιο. Περιοχή Χόρτου. Παράδειγμα συνδυαστικής απεικόνισης πληροφοριών.

Η προσπάθεια ξεκίνησε από μια απλή βάση δεδομένων βασισμένη στην Access της Microsoft, όπου συγκεντρώνονται όλες οι πληροφορίες που προκύπτουν καθημερινά κυρίως ως συνέπεια των αιτήσεων των πολιτών και των αρχαιολογικών αυτοψιών που διενεργούνται στη συνέχεια. Η βάση αυτή κρατήθηκε σκόπιμα σε πολύ απλό και στοιχειώδες επίπεδο, προκειμένου να είναι εύκολα αντιληπτή και να μπορεί να χρησιμοποιηθεί από όλους. Συνδυάζει πληροφορίες των εγγράφων που κατατίθενται στην Υπηρεσία ή παράγονται από αυτή (αιτήσεων, απαντήσεων, αναρτήσεων στο πρόγραμμα ΔΙΑΥΓΕΙΑ (http://diavgeia.gov.gr/), συνημμένων ή σχετικών εγγράφων, πορεία διεκπεραίωσης της υπόθεσης), γεωγραφικές και τοπογραφικές πληροφορίες (συντεταγμένες σε ΕΓΣΑ87, θέση στο Google Earth), διοικητικές πληροφορίες (δήμος, οικισμός) και τέλος αρχαιολογικές πληροφορίες ύπαρξης ή μη αρχαιοτήτων και μιας στοιχειώδους πρώτης χρονολόγησής τους.

Σε ένα δεύτερο επίπεδο δημιουργήθηκε η υποδομή για τη χρησιμοποίηση μέρους ή και του συνόλου των παραπάνω πληροφοριών μέσω λογισμικού GIS (Conolly & Lane 2006, Wheatley & Gillings 2002; Chapman 2006.). Για την ακρίβεια χρησιμοποιήθηκε το πρόγραμμα ArcInfo 8.0 (http://www.esri.com/software/arcgis/arcinfo), στο οποίο κατασκευάστηκαν σειρά επιπέδων (layers) από πληροφορίες που μπορούν να συνδυαστούν μεταξύ τους. Χρησιμοποιούνται υπόβαθρα χαρτών που δημιουργήθηκαν συνδυαστικά από την ψηφιοποίηση δεδομένων από χάρτες της Υπηρεσίας του Εθνικού Κτηματολογίου (http://www.ktimatologio.gr), της Γ.Υ.Σ. και από τη βάση των δημόσιων ανοικτών δεδομένων (http://geodata.gov.gr/geodata), ενώ δημιουργήθηκαν και χάρτες με ειδικές πληροφορίες. Με τον τρόπο αυτό είναι εύκολο να εντοπίζονται με μεγάλη ακρίβεια σημεία ενδιαφέροντος είτε μέσω συντεταγμένων είτε μέσω επισκόπησης των χαρτών και των αεροφωτογραφιών από το σύνολο της περιοχής. Πρέπει να σημειωθεί ότι μόλις τα τελευταία δύο περίπου χρόνια, σχεδόν το σύνολο των τοπογραφικών που κατατίθενται πλέον στην Υπηρεσία μας από τους τοπογράφους ή τους ιδιώτες χρησιμοποιεί το σύστημα συντεταγμένων ΕΓΣΑ87, γεγονός που διευκολύνει πλέον την συνολική διαδικασία που ακολουθείται.

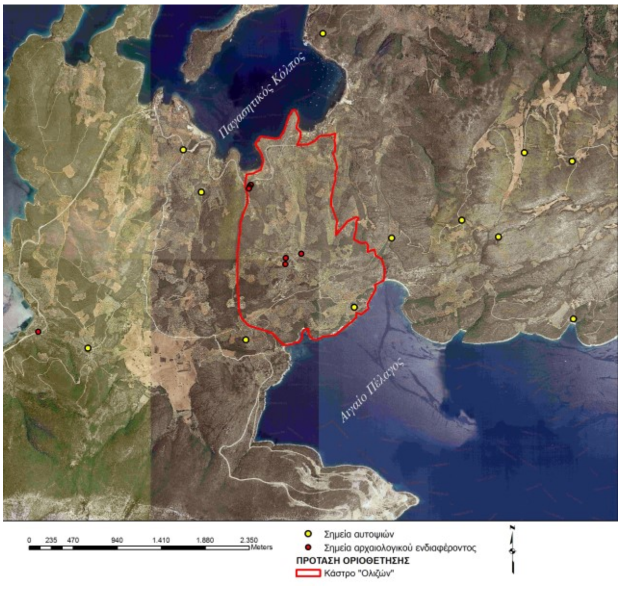
Μετά την αρχική μαζική εισαγωγή πληροφοριών από την προϋπάρχουσα βάση δεδομένων στο σύστημα γεωγραφικών πληροφοριών, τώρα πλέον να μπορούν να εισαχθούν σε αυτό πληροφορίες είτε απευθείας είτε και πάλι μέσω της εξωτερικής βάσης δεδομένων με την κατάλληλη μορφοποίηση του εισερχόμενου αρχείου. Η ευελιξία αυτή αποδείχθηκε χρήσιμη όταν σταδιακά αυξήθηκε η πολυπλοκότητα του συστήματος με τη χρήση PDA's (GPS eMap Garmin, PDA MIO 168) και smart phones (με λειτουργικό windows mobile 6.1 professional και android) για την εισαγωγή δεδομένων κατευθείαν από το πεδίο, αλλά και καθώς αυξάνονται οι χρήστες χωρίς να είναι αυτονόητο ότι επιθυμούν να εμπλακούν με πιο σύνθετες εργασίες μετατροπής ψηφιακών αρχείων.

Στο Γεωγραφικό αυτό Σύστημα Πληροφοριών, βασική μονάδα καταγραφής (record) αποτελεί κάθε ξεχωριστό γεωγραφικό σημείο αρχαιολογικού ελέγχου, χαρακτηριζόμενο από ένα μοναδικό ζεύγος συντεταγμένων σε ΕΓΣΑ87. Επιλέχθηκε οι εγγραφές να γίνονται με τη μορφή σημείων και όχι με πολύγωνα καθώς έτσι γίνεται πιο απλή και γρήγορη η διαδικασία, ενώ για κάθε οικόπεδο ή αγροτεμάχιο μπορούν να προστεθούν πολλά σημεία (και κατά συνέπεια περισσότερες εγγραφές στη βάση δεδομένων) αν χρειάζεται να διαφοροποιηθούν περιοχές εντός των ορίων του με βάση τα ευρήματα. Επιπλέον με τον τρόπο αυτό μπορούν να τοποθετηθούν στο χώρο ακόμα και μεμονωμένα ευρήματα που εντοπίζονται στη διάρκεια αυτοψιών, που δε συνδέονται με έλεγχο συγκεκριμένων ιδιοκτησιών.



Εικόνα 2 Επεξεργασία δεδομένων σε περιβάλλον GIS

Παράλληλα δημιουργήθηκαν και συνεχώς εμπλουτίζονται διαφορετικά επίπεδα (layers) με τη μορφή πολυγώνων με ακριβείς συντεταγμένες, που περιέχουν τους κηρυγμένους και τους υπό κήρυξη αρχαιολογικούς χώρους, τα όρια των σύγχρονων οικισμών (πολεοδομικά σχέδια), τα διοικητικά όρια των δήμων (Καλλικράτης και Καποδίστριας), τις χρήσεις γης, το δίκτυο των ρεμάτων και το οδικό δίκτυο με διαβαθμίσεις των οδών συμπεριλαμβανομένων και των μονοπατιών νεότερων ή παλαιότερων. Μπορεί έτσι να ελεγχθεί εύκολα η θέση κάθε νέας υπό εξέταση περιοχής σε σχέση με τους υπάρχοντες αρχαιολογικούς χώρους, τις κατά τόπους γεωγραφικές ιδιαιτερότητες και τα σημερινά ή παλαιότερα διοικητικά όρια. Ενδιαφέρον αποτελεί και το γεγονός ότι με συνδυασμό των παραπάνω καθίστανται πιο εύκολες οι αποφάσεις για την έκταση των υπό κήρυξη αρχαιολογικών χώρων ενώ παράλληλα τεκμηριώνονται σαφώς πιο αξιόπιστα (Εικ. 2).



Εικόνα 3 Οριοθέτηση περιοχής Αρχαιολογικού Χώρου με βάση τα δεδομένα του Συστήματος Γεωγραφικών Πληροφοριών

Έχοντας εισάγει από το γραφείο όλες αυτές τις πληροφορίες στο σύστημα και με παράλληλη ενημέρωση των φορητών συσκευών, καθίσταται τελικά εύκολος ο εντοπισμός όλων των παραπάνω στο πεδίο κατά τη διάρκεια των περιοδειών και των αυτοψιών.

2. Τα πρώτα ορατά αποτελέσματα

Αυτή τη στιγμή, μετά από δύο χρόνια ανάπτυξης και εφαρμογής της παραπάνω ψηφιακής προσέγγισης, είμαστε πλέον σε θέση να έχουμε μια σχετικά μεγάλη πολυεπίπεδη βάση δεδομένων, που πραγματικά καθιστά την καθημερινή αρχαιολογική εργασία περισσότερο εύκολη αλλά και σαφώς πιο δημιουργική. Πρέπει να σημειωθεί, ότι πέρα από την καθαρά διοικητική εργασία, τώρα πλέον οι αρχαιολογικοί έλεγχοι και οι αυτοψίες καθώς και οι μεγάλες και χρονοβόρες περιοδείες σε οποιαδήποτε περιοχή του Πηλίου, απέκτησαν νέο νόημα. Με το συνδυασμό των διαθέσιμων πληροφοριών δημιουργείται ανά πάσα στιγμή μια συνολική μεγάλη εικόνα προς όφελος της καλύτερης τεκμηρίωσης, προστασίας και ανάδειξης των αρχαιολογικών χώρων και μνημείων, την ίδια στιγμή που και διοικητικά οι έλεγχοι διεκπεραιώνονται ταχύτερα και ευκολότερα.

Με την νέα αυτή προσέγγιση μπορούμε να έχουμε καταρχήν όλα τα πλεονεκτήματα των ψηφιακών αρχειοθετήσεων με τη χρήση σύνθετων αναζητήσεων και ποικίλων ταξινομήσεων των καταχωρημένων πληροφοριών. Καθημερινά μάλιστα, καθώς οι πληροφορίες αυτές συνεχώς αυξάνονται με νέες καταχωρήσεις, αποδεικνύεται ολοένα και περισσότερο η χρησιμότητα του εγχειρήματος ειδικά όταν προστεθούν και οι δυνατότητες που δίνουν τα λογισμικά που χρησιμοποιούνται για μέτρηση των αποστάσεων αλλά και για έλεγχο της ορατότητας από συγκεκριμένα σημεία (π.χ. αρχαιολογικούς χώρους), που αποτελούν σημαντικούς παράγοντες για την έκδοση ή μη μιας έγκρισης εργασιών (εικ. 4).

Η δημιουργία ενός χάρτη με σημειωμένες επάνω όλες τις απαραίτητες πληροφορίες υπήρξε ανέκαθεν το ζητούμενο. Υπάρχουν παλαιότερες προσπάθειες όπου συνήθως πάνω στο χάρτινο αντίτυπο ενός χάρτη σημειώνονταν όσα περισσότερα στοιχεία χωρούσαν. Σχεδόν πάντα ωστόσο η προσπάθεια έφθανε σε ένα οριακό σημείο και εγκαταλείπονταν με το χάρτη σχισμένο από την συχνή χρήση ή γεμάτο με τόσες πληροφορίες που γινόταν πλέον αδύνατη η αξιοποίησή τους. Με την ψηφιακή τεχνολογία θεωρούμε ότι όχι μόνο δεν υφίστανται οι παραπάνω περιορισμοί αλλά είναι δυνατή και μια διαρκής ενημέρωση του συστήματος ανεξάρτητα από τους χρήστες του, αφού μπορούν πλέον να συμμετέχουν περισσότεροι του ενός συμβάλλοντας όλοι και εξασφαλίζοντας επίσης όλοι πολλαπλά οφέλη.

Συμπεράσματα

Στο επίπεδο της καθημερινής πρακτικής μιας δημόσιας υπηρεσίας, τα παραπάνω αποτελούν σαφώς και μια σημαντική πηγή εξοικονόμησης πόρων είτε μιλάμε για ανθρώπινο δυναμικό είτε για οικονομία σε σχέση με έξοδα μετακίνησης και ημερομισθίων. Η αποφυγή άσκοπων και μη αποδοτικών μετακινήσεων εξοικονομεί και εξασφαλίζει ανθρωποώρες εργασίας, καύσιμα, ημερομίσθια και φυσικά χρόνο και την καλή διάθεση των συμμετεχόντων.

Αν θέλαμε να επισημάνουμε κάποια αδυναμία του συστήματος, αυτή περιορίζεται στην ανάγκη μιας στοιχειώδους εκπαίδευσης των χρηστών του, τόσο στη χρήση της συγκεκριμένης τεχνολογίας όσο και σε βασικές έννοιες των ψηφιακών βάσεων δεδομένων και της τοπογραφικής προσέγγισης μιας θέσης μέσω συντεταγμένων. Στην πράξη αυτό έχει αποδειχθεί πολύ εύκολο, ειδικά με νεώτερους συναδέλφους που αντιλαμβάνονται αμέσως τα οφέλη χωρίς να έχουν να αντιπαρέλθουν το ψυχολογικό εμπόδιο μιας παγιωμένης διαδικασίας. Γιατί όσο και αν φανεί παράξενο, αυτό που φαίνεται να εμποδίζει μερικές φορές ακόμα και τον πειραματισμό με μια ψηφιακή λύση, είναι ένας ψυχολογικός φραγμός, που ωθεί στο να θεωρηθεί εκ των προτέρων οτιδήποτε ψηφιακό δύσκολο και οτιδήποτε διαφορετικό από την πεπατημένη περισσότερο πολύπλοκο και λιγότερο εφαρμόσιμο, άσχετα αν αναγνωρίζεται γενικά η χρησιμότητά του.

Η επέκταση συνεπώς της εφαρμογής του συστήματος στην υπόλοιπη περιοχή της Μαγνησίας με την εμπλοκή ολοένα και περισσοτέρων συναδέλφων και με σκοπό την πλήρη καθιέρωσή του ως τη βασική διαδικασία καταγραφής των δεδομένων της Υπηρεσίας, αποτελεί από μόνο του μια μεγάλη πρόκληση για το μέλλον. Ήδη έχουν γίνει τα πρώτα βήματα και αναμένεται εντός του 2014 να έχει επιτευχθεί η λειτουργία του συστήματος για το σύνολο της περιφερειακής ενότητας Μαγνησίας.

Ως προοπτική, θα μπορούσε ενδεχομένως να διερευνηθεί η δυνατότητα μελλοντικής ενσωμάτωσης όλων αυτών των πληροφοριών στο Αρχαιολογικό Κτηματολόγιο, η κατασκευή του οποίου έχει αναγγελθεί από το Υπουργείο Πολιτισμού και Αθλητισμού και προχωράει (http://archaeocadastre.culture.gr/el/). Βέβαια, όπως μπορεί κανείς να παρατηρήσει στη σχετική ιστοσελίδα, το Αρχαιολογικό Κτηματολόγιο στοχεύει στην καταγραφή των αρχαιολογικών χώρων και μνημείων και όχι της καθημερινής αρχαιολογικής διαδικασίας ελέγχου. Ελπίζουμε ωστόσο ότι με κάποια μορφή θα μπορέσουν τελικά να ενταχθούν εκτός από τα αυτονόητα στοιχεία με αρχαιολογικό ενδιαφέρον και οι πολυάριθμες αυτοψίες σε χώρους χωρίς εμφανές άμεσο αρχαιολογικό ενδιαφέρον, οι οποίες όμως προσφέρουν πολύτιμες πληροφορίες.

Κύριος και άμεσος στόχος προς το παρόν είναι ο συνεχής εμπλουτισμός τους συστήματος με νεότερα δεδομένα, καθώς αυτό φαίνεται να είναι το δυνατό του σημείο για οποιαδήποτε μελλοντική αξιοποίηση. Συμπερασματικά, θεωρούμε ότι με απλές ιδέες και εφαρμογές, αλλά κυρίως με διάθεση για προσφορά στο πεδίο της επιστήμης και της εργασίας, είναι δυνατό να συμβάλει κανείς τόσο στο παρόν όσο και στο μέλλον της προστασίας και της ανάδειξης της πολιτιστικής κληρονομιάς στον περιβάλλον εργασίας του αλλά και γενικότερα.

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ΕΦΑΡΜΟΓΗ ΤΗΣ ΦΩΤΟΕΡΜΗΝΕΙΑΣ ΚΑΙ ΤΗΛΕΠΙΣΚΟΠΗΣΗΣ ΓΙΑ ΤΟΝ ΕΝΤΟΠΙΣΜΟ ΘΑΜΜΕΝΩΝ ΑΡΧΑΙΟΛΟΓΙΚΩΝ ΚΑΤΑΛΟΙΠΩΝ ΣΤΟ ΠΛΑΤΩΜΑ ΤΟΥ ΒΟΡΕΙΟΥ ΒΡΑΧΙΟΝΑ ΤΟΥ ΟΡΜΟΥ ΤΗΣ ΒΟΪΔΟΚΟΙΛΙΑΣ ΤΟΥ ΝΟΜΟΥ ΜΕΣΣΗΝΙΑΣ, ΠΕΛΟΠΟΝΝΗΣΟΥ, ΕΛΛΑΔΑΣ

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Περίληψη/ Abstract

Η συγκεκριμένη εργασία είχε ως στόχο να αναπτύξει μεθόδους ανίχνευσης θαμμένων αρχαιολογικών καταλοίπων, με αξιοποίηση των δυνατοτήτων της Φωτοερμηνείας και Τηλεπισκόπησης καθώς και των ψηφιακών επεξεργασιών τηλεπισκοπικών απεικονίσεων (στη συγκεκριμένη περίπτωση αεροφωτογραφιών και δορυφορικών εικόνων IKONOS) σε περιβάλλον GIS. Τα αποτελέσματα διασταυρώθηκαν με επίγειο έλεγχο ολόκληρης της μελετώμενης περιοχής και τέλος με γεωφυσική διασκόπηση τμήματός της. Έτσι, προτείνεται μια εξειδικευμένη μεθοδολογία για τον εντοπισμό αρχαιολογικών καταλοίπων, και, ειδικότερα, νεκροταφείων και οικισμών της Εποχής του Χαλκού σε ασβεστολιθικά εδάφη, έναν τύπο εδάφους που απαντάται ιδιαίτερα συχνά στον Ελλαδικό χώρο. Επιπλέον στόχος της συγκεκριμένης έρευνας ήταν το ψηφιακό αυτό "εργαλείο" να δοθεί σε μια απλουστευμένη μορφή, προτείνοντας πολύ συγκεκριμένες μεθόδους ψηφιακής επεξεργασίας εικόνων, έτσι ώστε ο μελετητής να μπορέσει με εύκολο και φιλικό τρόπο να το χρησιμοποιήσει. Περιοχή μελέτης απετέλεσε η ευρύτερη περιοχή του όρμου της Βοϊδοκοιλιάς του νομού Μεσσηνίας.

The aim of this study was to develop methods for the detection of buried archaeological relics by making use of the potential of Remote Sensing and Photointerpretation as well as of the digital processing of remotely sensed imagery (in this case aerial photographs and satellite images) within a GIS environment. The results were checked with ground survey results of the study area and, finally, with geophysical prospection of a part of it. Therefore, a specialized methodology for the detection of buried archaeological relics, and, more specifically, of cemeteries and settlements of the Bronze Age in calcareous soils is proposed. Another objective was that this digital "tool" will be provided in a simplified form, proposing very specific methods of digital image processing, in a simply and user-friendly manner, especially for archaeologists. The study area was the wider region of Voidokilia bay in the Prefecture of Messinia, Greece.
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Λέξεις Κλειδιά: Αρχαιολογία, Φωτοερμηνεία, Τηλεπισκόπηση, Επίγειος Έλεγχος, Γεωφυσική Διασκόπηση, Αεροφωτογραφίες, Δορυφορικές Εικόνες, IKONOS, Ελλάδα, Μεσσηνία, Βοϊδοκοιλιά, Εποχή του Χαλκού

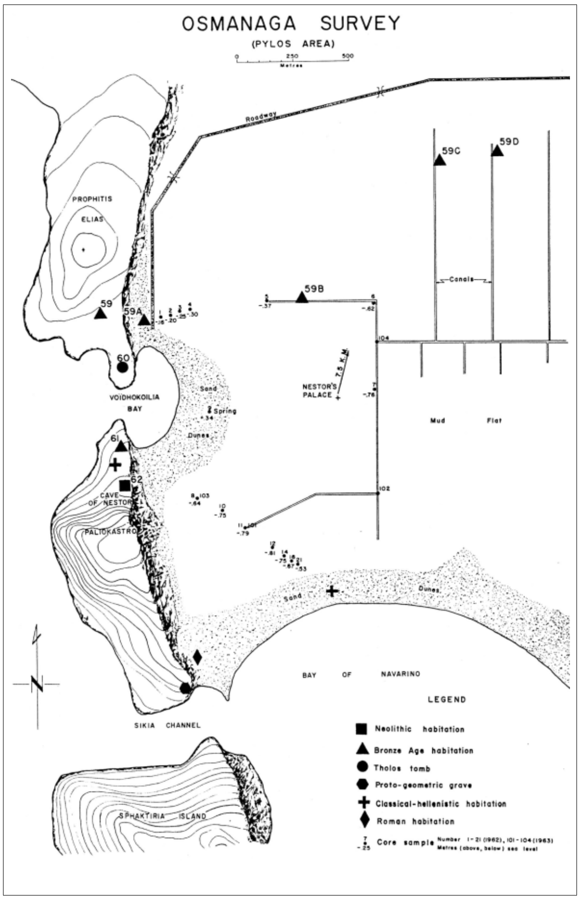
Εισαγωγή

Τηλεπισκοπικές απεικονίσεις έχουν χρησιμοποιηθεί στο παρελθόν προκειμένου να ανιχνευθούν θαμμένα αρχαιολογικά κατάλοιπα (Bradford 1957, St Joseph 1966, Renfrew & Bahn 1966, Riley 1987, Allen *et al* 1990, Alexakis *et al* 2009). Στόχος της συγκεκριμένης μελέτης ήταν να προταθεί μια εξειδικευμένη μεθοδολογία για την ανίχνευση θαμμένων αρχαιολογικών καταλοίπων, και, ειδικότερα, νεκροταφείων και οικισμών της Εποχής του Χαλκού σε ασβεστολιθικά εδάφη (Χρόνη 2011).

1. Περιοχή Μελέτης

Περιοχή μελέτης απετέλεσε ο νομός Μεσσηνίας, ένας χώρος με μακρότατο ιστορικό παρελθόν και πλούτο αρχαιολογικών θέσεων και καταλοίπων. Το μεγαλύτερο μέρος των αρχαιολογικών θέσεων των μνημονευόμενων από τους αρχαίους συγγραφείς και περιηγητές και προκυπτόντων από ολοκληρωμένη μελέτη ιστοριογραφικής και βιβλιογραφικής πληροφορίας, έχει ήδη εντοπισθεί και, εν μέρει, ανασκαφεί. Ωστόσο, υπάρχει ακόμη ένα μικρό ποσοστό θέσεων που δεν έχουν εντοπισθεί, αν και εικάζεται το χωρικό τους σημείο, όπως αυτό προκύπτει από ποικίλα ιστοριογραφικά, βιβλιογραφικά και αρχαιολογικά στοιχεία. Ένα τέτοιο σημείο αποτελεί και ο όρμος της Βοϊδοκοιλιάς, στις δυτικές ακτές του νομού Μεσσηνίας (η οποία πρέπει να κατοικήθηκε ήδη από την Παλαιολιθική εποχή), προς το Ιόνιο πέλαγος: πρόκειται για έναν μικρό, προς τα δυτικά στραμμένο όρμο ο οποίος βρίσκεται βορειοδυτικά και, ακριβέστερα, έξω από τον όρμο του

Ναυαρίνου, ένα από τα μεγαλύτερα φυσικά λιμάνια. (Εικ. 1, 2)



Εικόνα 1 Η ευρύτερη περιοχή του όρμου της Βοϊδοκοιλιάς (Mc Donald W. & Hope Simpson R., A.J.A. 1964, plate 71)

Πιο συγκεκριμένα: ολόκληρη η περιοχή της Βοϊδοκοιλιάς (από τον βορειότερα κείμενο λόφο του Προφήτη Ηλία μέχρι και το προς Νότο διακρινόμενο, κάτω από το Παλαιόκαστρο, Σπήλαιο του Νέστορος) είχε κατοικηθεί ήδη κατά την Ύστερη Νεολιθική Εποχή, γύρω στο 3.000 π.Χ.. Αυτό προκύπτει από παλαιότερες έρευνες των Blegen και Θεοχάρη (Blegen *et al.* 1973, Θεοχάρης 1989). Η Μεσσηνία ήταν τότε αραιότατα κατοικημένη. Εκτεταμένη έρευνα της περιοχής, με τη συνεργασία πολλών επιστημόνων διαφορετικών ειδικοτήτων, πραγματοποιήθηκε από το Πανεπιστήμιο της Minnesota, υπό την επίβλεψη των W. Mc Donald και R. Hope Simpson, λίγο πριν τη δεκαετία του 1960 (Mc Donald *et al.* 1972). Ανασκαφές στην περιοχή κατά την ίδια, περίπου, χρονική περίοδο πραγματοποίησε και ο Σπ. Μαρινάτος (Μαρινάτος 1956; 1958). Το έργο του τελευταίου συνέχισε και συνεχίζει μέχρι σήμερα ο κ. Γ.Στ. Κορρές (Κορρές 1993).

 ΠΕ ΙΙ οικισμός/ΜΕ τύμβος (Α΄Βοϊδοκοιλιάς)/ΥΕ θολωτός τάφος/Ελληνιστική κεραμεική, ειδώλια και λατρευτικά πλακίδια.

 Πλάτωμα με πιθανά αρχαιολογικά κατάλοιπα.

 Εκκλησάκι Προφήτη Ηλία.

Εικόνα 2 Η ευρύτερη περιοχή του βόρειου βραχίονα του όρμου της Βοϊδοκοιλιάς. (Χρόνη 2011, σελ. 225)

Ως *δοκιμαστική* περιοχή έρευνας (έκτασης περίπου 800 $μ^2$) επιλέχθηκε η ανασκαμμένη σήμερα περιοχή στο βόρειο βραχίονα του όρμου της Βοϊδοκοιλιάς, η οποία περιλαμβάνει, πολύ συνοπτικά, αρχαιολογικά κατάλοιπα :

- Πρωτοελλαδικού ΙΙ (ΠΕ ΙΙ) οικισμού,
- Μεσοελλαδικού (ΜΕ) τύμβου και
- Υστεροελλαδικού (ΥΕ) θολωτού τάφου.

Δεν έχουν ακόμη εντοπισθεί τα αντίστοιχα των προαναφερθέντων αρχαιολογικών καταλοίπων, δηλαδή:

- το υπόλοιπο τμήμα του ΠΕ ΙΙ οικισμού
- το ΠΕ ΙΙ νεκροταφείο,
- ο ΜΕ οικισμός και
- ο ΥΕ οικισμός

Ως περιοχή πιθανή να περιέχει τα ζητούμενα αρχαιολογικά κατάλοιπα εικάζεται το πλάτωμα (έκτασης περίπου 5000 $μ^2$) το ευρισκόμενο βορείως της ανασκαμμένης περιοχής, το οποίο απέχει από αυτή περίπου 100 μ.

2. Διεκπεραίωση της έρευνας

Όσον αφορά στις αναλογικές τηλεπισκοπικές απεικονίσεις, χρησιμοποιήθηκαν στερεοσκοπικά ζεύγη παγχρωματικών αεροφωτογραφιών έξι διαφορετικών ετών, ποικίλων κλιμάκων. Η επιλογή των αεροφωτογραφιών πραγματοποιήθηκε με πολύ συγκεκριμένο σκεπτικό, που βασίστηκε στο χρονικό των ανασκαφών στην περιοχή της Βοϊδοκοιλιάς. Αυτό έχει ως εξής :

1956–1958: εντοπισμός και ανασκαφή του ΥΕ θολωτού τάφου του λεγόμενου *του Θρασυμήδους,*
1976–1983: ανασκαφή του ΜΕ τύμβου γύρω από τον προαναφερθέντα θολωτό τάφο.

Η συγκριτική μελέτη τηλεπισκοπικών απεικονίσεων συγκεκριμένων περιόδων υπαγορεύεται από το γεγονός ότι καθίσταται δυνατή η παρατήρηση της μορφής της επιφάνειας του εδάφους πριν και μετά από την κάθε ανασκαφική φάση: είναι σαφές ότι τα αποτελέσματα αυτής της πρώτης προσέγγισης μπορούν να φανούν ιδιαίτερα χρήσιμα στη φωτοερμηνευτική παρατήρηση του πλατώματος βορείως της ανασκαμμένης πλέον περιοχής, για το οποίο και πιθανολογείται στην παρούσα μελέτη η ύπαρξη ΠΕ ΙΙ νεκροταφείου/ΠΕ ΙΙ οικισμού/ΜΕ οικισμού/ΥΕ οικισμού. Ο παραλληλισμός και συσχετισμός κάποιων ιχνών όπως αυτά παρουσιάστηκαν – στην πλέον ανασκαμμένη περιοχή – πριν το 1956 με ίχνη στο προαναφερθέν βόρειο πλάτωμα, είναι δυνατόν να υποβοηθήσει και να υποστηρίξει τη φωτοερμηνευτική διαδικασία.

Όσον αφορά στις ψηφιακές τηλεπισκοπικές απεικονίσεις, επιλέχθηκαν αυτές που προέρχονται από τον δορυφόρο IKONOS λόγω της μεγάλης διακριτικής τους ικανότητας (1 μέτρο στις παγχρωματικές, 4 μέτρα στις πολυφασματικές).

Στη συγκεκριμένη μελέτη χρησιμοποιήθηκαν δύο σειρές παγχρωματικών και πολυφασματικών σε τέσσερα κανάλια (κόκκινο, πράσινο, μπλε και εγγύς υπέρυθρο) ψηφιακών τηλεπισκοπικών απεικονίσεων IKONOS (όλες αποδιδόμενες με 8 bits ανά pixel για το κάθε κανάλι).

3. Αναλογική φωτοερμηνεία

Η αναλογική φωτοερμηνεία των τηλεπισκοπικών απεικονίσεων βασίστηκε στην αξιολόγηση των βασικών φωτοαναγνωριστικών στοιχείων, δίνοντας έμφαση στον τόνο, την υφή, τη σκιά, τα πρότυπα, τη θέση/τοποθεσία και τη σχέση με το περιβάλλον. Ειδικότερα, τα στερεοσκοπικά ζεύγη των αεροφωτογραφιών μελετήθηκαν περαιτέρω και με τη χρήση διαφορετικών στερεοσκοπικών οργάνων.

4. Ψηφιακή επεξεργασία των τηλεπισκοπικών απεικονίσεων

Για την ψηφιακή επεξεργασία του συνόλου των τηλεπισκοπικών απεικονίσεων (αεροφωτογραφιών και λήψεων IKONOS) χρησιμοποιήθηκε το λογισμικό *ER Mapper*, εφαρμόζοντας διαφορετικούς αλγόριθμους ενίσχυσης/βελτίωσης ψηφιακών τηλεπισκοπικών απεικονίσεων (*image enhancement*) (Jensen 1996, Argialas 1999).

Στόχος κατά την ψηφιακή επεξεργασία των μελετώμενων τηλεπισκοπικών απεικονίσεων ήταν η επιλογή των αλγόριθμων εκείνων που θα συνέβαλαν στην ανάδειξη και διερεύνηση των γραμμικών σχηματισμών και των εναλλαγών σκιάς λόγω ανωμαλιών του μικροαναγλύφου που ανιχνεύθηκαν κατά την αναλογική διαδικασία της φωτοερμηνείας.

Ειδικότερα, η ισοδυναμοποίηση του ιστογράμματος καθώς και το *χωρικό φίλτρο ενίσχυσης υψηλών συχνοτήτων* (δεδομένου ότι, όσον αφορά τουλάχιστον στα γραμμικά ίχνη, στόχος ήταν ο τονισμός επίμηκων λεπτομερειών των απεικονίσεων) και το *χωρικό φίλτρο γραμμικής ενίσχυσης των ακμών κατά τον άξονα y* (που προσδίδει πλαστικότητα στην απεικόνιση σε σχέση με τη θέση του φωτισμού), συνέβαλαν αποτελεσματικά στην οπτική βελτίωση των εικόνων και τον τονισμό των γραμμικών ιχνών, τα οποία και καταστήθηκαν εντονότερα. Ιδιαίτερα με την εφαρμογή του χωρικού φίλτρου γραμμικής ενίσχυσης των ακμών κατά τον άξονα y τα συγκεκριμένα ίχνη έλαβαν ανάγλυφη, ακόμη πιο ευδιάκριτη μορφή, ενώ ταυτόχρονα καταστήθηκαν ορατά ίχνη σκιών μικροαναγλύφου, τόσο στη λήψη της 23-5-2000 όσο και στη λήψη της 3-6-2000, στην ίδια –ελλειψοειδούς σχήματος- περιοχή όπου εντοπίσθηκαν και στις αεροφωτογραφίες της 26-9-1975 και 29-6-1989 (Χρόνη 2011).

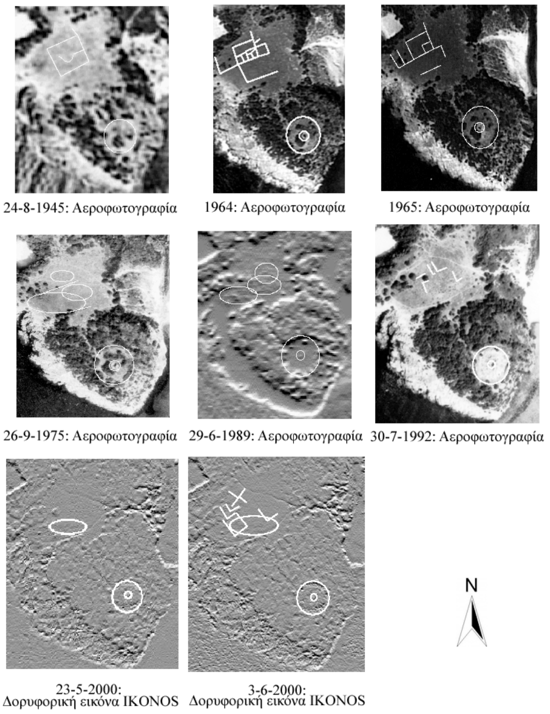
Αποτελέσματα

Σχετικά με το βορείως κείμενο πλάτωμα, ανιχνεύθηκαν (Εικ. 3):

- 1945 (κλίμακα 1:42.000): Γραμμικά ίχνη (κατέστησαν εντονότερα μετά την εφαρμογή της ψηφιακής επεξεργασίας).
- 1964 (κλίμακα 1:15.000): Γραμμικά ίχνη (κατέστησαν εντονότερα μετά την εφαρμογή της ψηφιακής επεξεργασίας).
- 1965 (κλίμακα 1:15.000): Γραμμικά ίχνη (κατέστησαν εντονότερα μετά την εφαρμογή της ψηφιακής επεξεργασίας).
- 1975 (κλίμακα 1:8.000): Ίχνη σκιών μικροαναγλύφου (κατέστησαν εντονότερα μετά την εφαρμογή της ψηφιακής επεξεργασίας). Τα συγκεκριμένα ίχνη σκιών μικροαναγλύφου τονίζουν δύο ευθύγραμμους

σχηματισμούς που συμπίπτουν χωρικά με αυτούς που παρατηρήθηκαν (ως γραμμικά ίχνη) στις προηγούμενες λήψεις.

- 1989 (κλίμακα 1:30.000): Ίχνη σκιών μικροαναγλύφου (κατέστησαν εντονότερα μετά την εφαρμογή της ψηφιακής επεξεργασίας).
- 1992 (κλίμακα 1:8.000): Γραμμικά ίχνη (κατέστησαν εντονότερα μετά την εφαρμογή της ψηφιακής επεξεργασίας).
- 23 Μαΐου 2000: Ίχνη σκιών μικροαναγλύφου (ανιχνεύθηκαν μόνο μετά την εφαρμογή της ψηφιακής επεξεργασίας).
- 3 Ιουνίου 2000: Γραμμικά ίχνη (κατέστησαν εντονότερα με την εφαρμογή της ψηφιακής επεξεργασίας της εικόνας) και ίχνη σκιών μικροαναγλύφου (ανιχνεύθηκαν μόνο μετά την εφαρμογή της ψηφιακής επεξεργασίας της εικόνας).



Εικόνα 3 Συνοπτική παρουσίαση των ανιχνευθέντων γραμμικών ιχνών και ιχνών σκιών μικροαναγλύφου (Χρόνη 2011, σελ. 476–478).

Μετά την εφαρμογή των ψηφιακών τεχνικών ενίσχυσης/τονισμού των γραμμικών ιχνών και ιχνών σκιών μικροαναγλύφου που ανιχνεύθηκαν στις αναλογικές και ψηφιακές τηλεπισκοπικές απεικονίσεις, διαδικασία η οποία ολοκληρωνόταν σε κάθε φάση με την οπτική φωτοερμηνεία, πραγματοποιήθηκε η καταγραφή των αποτελεσμάτων της φωτοερμηνείας με ψηφιοποίηση των γραμμικών στοιχείων, όσον αφορά στα γραμμικά ίχνη, και ψηφιακή οριοθέτηση των περιοχών όπου παρατηρήθηκαν τα ίχνη σκιών μικροαναγλύφου.

Με τη θεώρηση των προαναφερθέντων ιχνών υπό τη μορφή αρχείων *vector* συμπληρώθηκε η μελέτη τους, καθιστώντας δυνατό το συσχετισμό των σχημάτων τους και των θέσεων, όπου αυτά εμφανίζονται, με πολύ μεγαλύτερη σαφήνεια.

5. Συσχετισμός των αποτελεσμάτων της φωτοερμηνείας με ποικίλα δεδομένα

Προκειμένου να διαπιστωθεί ο βαθμός στον οποίο τα εντοπισθέντα ίχνη είναι πιθανό να αποκαλύπτουν θαμμένα αρχαιολογικά κατάλοιπα, τα αποτελέσματα της φωτοερμηνείας, όπως έχουν συνοπτικά παρατεθεί, συνδυάστηκαν με μία σειρά διαφορετικών δεδομένων, όπως:

1. Τα μετεωρολογικά δεδομένα, που επικρατούσαν κατά την περίοδο λήψης των διαφορετικών τηλεπισκοπικών απεικονίσεων: αξιοσημείωτο είναι ότι η μέση μηνιαία υγρασία κατά τα έτη 1964 και 1965 κυμάνθηκε σε παρόμοια, ιδιαίτερα υψηλά επίπεδα, γεγονός το οποίο θα πρέπει να συνέβαλε ουσιαστικά στην ιδιαίτερα έντονη εμφάνιση των ανιχνευθέντων γραμμικών ιχνών, τα οποία εμφανίζονται περισσότερο «ολοκληρωμένα» ως σχήματα, από ότι σε οποιαδήποτε άλλη λήψη διαφορετικού έτους.

2. Τα γεωλογικά δεδομένα της περιοχής κατά τη σημερινή εποχή: η υπό μελέτη περιοχή καλύπτεται από ασβεστόλιθους. Σε ασβεστολιθικά εδάφη τα ίχνη είναι σαφή και ευδιάκριτα αλλά πολύ αποσπασματικά. Η ερμηνεία γι' αυτή τη διαφοροποίηση είναι πιθανόν το ότι ο ασβεστολιθικός βράχος κάτω από την επιφάνεια ήταν στα περισσότερα σημεία ιδιαίτερα σκληρός για τη διάνοιξη τάφρων και λάκκων από τους πρώτους κατοίκους της περιοχής και το ότι οι περισσότερες από τις αρχαίες οριοθετήσεις του χώρου πραγματοποιήθηκαν με πέτρινους τοίχους που κατόπιν καταστράφηκαν και παρασύρθηκαν από τη μεταγενέστερη χρήση της γης.

3. Τα κλιματολογικά δεδομένα της περιοχής τόσο κατά τη σημερινή εποχή όσο και κατά τις περιόδους της αρχαιότητας που μας ενδιαφέρουν στη συγκεκριμένη μελέτη: το σημερινό μεσογειακό κλίμα επικρατούσε σε ολόκληρο τον Ελλαδικό χώρο κατά τη διάρκεια του Ολοκαίνου (από το 10.000 π.Χ. και εξής).

4. Τα γεωλογικά και γεωμορφολογικά δεδομένα της περιοχής που επικρατούσαν κατά τις περιόδους της αρχαιότητας που μας ενδιαφέρουν στη συγκεκριμένη μελέτη: στην Ελλάδα το εδαφικό ανάγλυφο αποτελούν, κατά το πλείστον, βουνά από σκληρό ασβεστόλιθο κρυσταλλικής μορφής.

Περισσότερο γόνιμα, αν και λιγότερο εκτεταμένα, ήταν τα εδάφη που εκτείνονταν στους λόφους και τους πρόποδες των βουνών, εδάφη που προέκυψαν κυρίως από τριτογενείς μάργες, άμμο και φλύσχη: για το λόγο αυτό εξάλλου οι περισσότεροι προϊστορικοί και πρώιμοι ιστορικοί οικισμοί συναντώνται πάνω ή δίπλα σε λόφους, παρά στο κέντρο μιας πεδιάδας, ή ακόμη και ανάμεσα σε βραχώδεις περιοχές. Λίγες είναι οι εξαιρέσεις και συνήθως παρατηρούνται όταν πρόκειται για κάποιο λιμάνι ή κάποια θέση-κλειδί για αλιεία. Επιπλέον, η περιοχή της σημερινής λιμνοθάλασσας ήταν ξηρά, που, όμως, διεσχίζετο από ποτάμια και είχε και πηγές νερού. Το νερό θα καθιστούσε εύφορη την καλλιεργήσιμη γη και θα παρείχε εύκολη ύδρευση στους κατοίκους της περιοχής. Αυτά τα δεδομένα, σε συνδυασμό με την ύπαρξη ενός μεγάλου φυσικού όρμου, που αποτελεί προστατευμένο λιμάνι, καθιστούν την θέση εξαιρετικά ευνοϊκή προς κατοίκηση από ένα πληθυσμό, όπως των ΠΕ ΙΙ χρόνων, ο οποίος στήριζε την οικονομία του τόσο στην γεωργία, όσον και στις θαλάσσιες επικοινωνίες.

5. Τη χλωρίδα και την πανίδα της περιοχής κατά τις περιόδους της αρχαιότητας που μας ενδιαφέρουν στη συγκεκριμένη μελέτη: Στοιχεία από τη μελέτη της διαδοχής των εναποθέσεων γύρης (pollen sequence), με δείγματα από τη λιμνοθάλασσα του Διβαρίου αποδεικνύουν ότι στην περιοχή υπήρχαν δρύες, ελαιόδεντρα και σιτηρά, ενώ οι πινακίδες της Πύλου αναφέρουν αγροτικά προϊόντα όπως σιτηρά, ελιές, σταφύλια, σύκα αλλά και εξημερωμένα ζώα, όπως βοοειδή, πρόβατα, αίγες και χοίροι, καθώς και κυνήγι και ψάρια.

6. Το μοντέλο εγγύτητας ή όχι πηγής πόσιμου νερού και τον τρόπο υδροδότησης των οικισμών κατά τις περιόδους της αρχαιότητας που μας ενδιαφέρουν στη συγκεκριμένη μελέτη: κατά την περίοδο της αρχαιότητας στην οποία αποδίδονται τα αναζητούμενα αρχαιολογικά κατάλοιπα, η εγγύτητα πόσιμου νερού δεν αποτελεί πάντα τον πρωταρχικό και καθοριστικό παράγοντα για την επιλογή μιας θέσης κατοίκησης, ούτε επίσης έχουν εντοπισθεί ποτέ θέσεις με αφθονία πόσιμου νερού αλλά χωρίς καλλιεργήσιμη έκταση ή καλό λιμάνι. Επιπροσθέτως, αξιοσημείωτο είναι ότι κατά τη Μυκηναϊκή περίοδο τα υδρευτικά συστήματα ήταν πολύπλοκα.

7. Το οδικό δίκτυο κατά τις περιόδους της αρχαιότητας που μας ενδιαφέρουν στη συγκεκριμένη μελέτη: εντατική έρευνα στην περιοχή από τη διεπιστημονική ομάδα του Πανεπιστημίου της Minnesota το 1963 απέδειξε ότι το οδικό δίκτυο της περιόδου ήταν αρκετά σύνθετο και αναπτυσσόταν ακριβώς δίπλα από τον σημερινό αυτοκινητόδρομο.

8. Το μοντέλο των οικισμών και νεκροταφείων και της μεταξύ τους διασύνδεσης κατά τις περιόδους της αρχαιότητας που μας ενδιαφέρουν στη συγκεκριμένη μελέτη: Τα μεγαλύτερα κέντρα σε κάθε περιοχή, κατά τη Μυκηναϊκή περίοδο, απείχαν μεταξύ τους 1–1,5 ώρα περπάτημα (τόσο περίπου απέχει η συγκεκριμένη θέση από το Ανάκτορο του Νέστορος), ενώ συχνές είναι οι περιπτώσεις οικισμών που εκμεταλλεύονται ξεχωριστά διαφορετικές ζώνες της περιοχής τους (ποιότητα εδάφους κατάλληλη για ανάπτυξη καλλιεργειών ή παράκτια περιοχή κατάλληλη για αλιεία και ναυσιπλοΐα) και, τέλος, ο χώρος ενταφιασμού βρίσκεται πάντοτε κοντά στον αντίστοιχο οικισμό. Η θέση ενός μυκηναϊκού θολωτού τάφου, ο οποίος συνήθως συνοδεύει μεγαλύτερα κέντρα, συχνά βρίσκεται σε κάποια απόσταση από αυτά.

9. Τη μορφή των οικοδομημάτων και ταφικών μνημείων κατά τις περιόδους της αρχαιότητας που μας ενδιαφέρουν στη συγκεκριμένη μελέτη: τα σχήματα που προκύπτουν από τα εντοπισθέντα γραμμικά ίχνη παραπέμπουν σε κατόψεις οικιών ή τάφων των συγκεκριμένων περιόδων.

10. Τη μορφή της κοινωνικής διαστρωμάτωσης και οργάνωσης καθώς και του διοικητικού μοντέλου που επικρατούσε κατά τις περιόδους της αρχαιότητας που μας ενδιαφέρουν στη συγκεκριμένη μελέτη, καθώς και τη μορφή των επαγγελματικών δραστηριοτήτων και της οργάνωσης και ελέγχου της οικονομίας, αλλά και τις οικονομικές, κοινωνικές, πολιτικές σχέσεις των διαφορετικών περιοχών και τους τρόπους επικοινωνίας για τις ίδιες περιόδους της αρχαιότητας: είναι ιδιαίτερα ανεπτυγμένες η γεωργία, η κτηνοτροφία και το εμπόριο. Η ναυσιπλοΐα είναι επίσης ιδιαίτερα ανεπτυγμένη προκειμένου να διεκπεραιώνονται το εμπόριο και οι ανταλλαγές των προϊόντων. Παρατηρείται εκτεταμένη εισαγωγή οψιανού στην Πελοπόννησο με σκοπό την κατεργασία του σε τοπικά εργαστήρια για την παραγωγή εργαλείων. Ειδικότερα κατά την ΥΕ περίοδο, ο Εγκλιανός λειτουργούσε σαν χρηματοκιβώτιο-αποθήκη και κέντρο ανταλλαγής εμπορευμάτων για τα περισσότερα προϊόντα τα οποία προήρχοντο και από τα ανακτορικά καταστήματα και από τις επαρχιακές πόλεις και οικισμούς, που ευρίσκοντο υπό την οικονομική του επικυριαρχία. Είναι πιθανόν ότι μία οικογένεια ή μία ομάδα ευγενών είχε στην κατοχή της κάποια περιοχή με τη μορφή της ατομικής περιουσίας και είχε αναπτύξει δραστηριότητες όμοιες με εκείνες του ανακτόρου, στον ίδιο περίπου χώρο, σε μικρότερη κλίμακα. Ίσως οι περισσότερες πόλεις είχαν οργανωθεί κατ' αυτόν τον χαλαρό τρόπο σε μικρούς ανεξάρτητους οικισμούς γύρω από ένα οχυρωμένο κέντρο, με κάθε οικισμό υποτελή στον τοπικό άρχοντα κατά

το φεουδαρχικό σύστημα και υποχρεωμένο να καταβάλει φόρους, αλλά αυτοδιοίκητο στον οικονομικό τομέα και τις εμπορικές δραστηριότητες (Χρόνη 2011).

6. Επίγειος έλεγχος – διασταύρωση των αποτελεσμάτων

Κατά την 3η Δεκεμβρίου 2000, πραγματοποιήθηκε επίγειος έλεγχος του βόρειου πλατώματος με στόχο την επαλήθευση και συμπλήρωση της φωτοερμηνείας.

Προέκυψαν τα ακόλουθα:
1. Δεν εντοπίσθηκαν ενδείξεις χρήσης της περιοχής κατά τη σύγχρονη προς εμάς εποχή, ούτε προέκυψε κάτι τέτοιο από τις πληροφορίες των σημερινών κατοίκων της ευρύτερης περιοχής.

2. Δεν εντοπίσθηκαν οι γραμμικοί σχηματισμοί (γραμμικά ίχνη) που ανιχνεύθηκαν στην ψηφιακή τηλεπισκοπική απεικόνιση της 3-6-2000: έτσι, επιβεβαιώνεται η υπόθεση ότι πρόκειται για ίχνη υγρασίας, σε συνδυασμό με το στοιχείο των ανοιχτών τόνων με τους οποίους εμφανίζονται.

3 Επιβεβαιώθηκε η αρχική, βασιζόμενη στη φωτοερμηνευτική ανάλυση, διάκριση των διαφορετικών ανιχνευθέντων γραμμικών ιχνών σε:
α. γραμμικά ίχνη δηλώνοντα αρχαιολογικά κατάλοιπα, και,
β. γραμμικά ίχνη δηλώνοντα πορείες μονοπατιών.

4. Τα προαναφερθέντα ενισχύουν τις υποθέσεις μας όσον αφορά και στα γραμμικά ίχνη τα ανιχνευθέντα στις αεροφωτογραφίες της 24-8-1945, του θέρους 1964, του θέρους 1965 και της 30-7-1992, ίχνη τα οποία έχουν την ίδια ακριβώς μορφή με αυτά της IKONOS 3-6-2000.

5. Εντοπίσθηκαν οι δύο γραμμικοί σχηματισμοί, που αποκαλύπτονται χάρη σε σκιές μικροαναγλύφου στην αεροφωτογραφία της 26-9-1975: το γεγονός ότι οι δύο αυτοί γραμμικοί σχηματισμοί αποκαλύπτονται μόνο σε μία τηλεπισκοπική απεικόνιση, από το σύνολο των 8 διαφορετικών τηλεπισκοπικών απεικονίσεων που διαθέτουμε για τη συγκεκριμένη έρευνα, χάρη σε σκιές μικροαναγλύφου επιβεβαιώνει την αναγκαιότητα περιοδικών φωτογραφήσεων μιας περιοχής.

6. Παρατηρώντας την επιφάνεια του εδάφους από ένα πολύ χαμηλό σημείο κοντά σε αυτή επιβεβαιώνεται η μορφή του μικροαναγλύφου όπως αυτό αποκαλύπτεται στις τηλεπισκοπικές απεικονίσεις, ακόμη και πριν την εφαρμογή *χωρικού φίλτρου γραμμικής ενίσχυσης των ακμών κατά τον άξονα y* (26-9-1975, 29-6-1989) και μετά από αυτό (23-5-2000, 3-6-2000).

7. Η βλάστηση στο εν λόγω πλάτωμα περιορίζεται μόνο σε χορτάρι και χαμηλούς θάμνους. Στα σημεία όπου παρατηρήθηκαν σκιές μικροαναγλύφου δεν υφίστανται θάμνοι, παρά μόνο χορτάρι.

8. Η περιοχή του βορείως κειμένου πλατώματος είναι διάσπαρτη με λίθους μορφής όμοιας με αυτή των λίθων που αποκαλύφθηκαν κατά την ανασκαφή του ΜΕ τύμβου και του ΥΕ θολωτού τάφου, οι οποίοι αποτελούσαν το δομικό υλικό των αρχαιολογικών λειψάνων.

9. Ο εντοπισμός, στο κέντρο περίπου του πλατώματος, κυκλικού βαθουλώματος διαμέτρου περίπου 1 μέτρου, πιθανώς να υποδηλώνει *βόθρο* (αποθηκευτικό λάκκο) οικίας ή τη θεμελίωση της εστίας του κεντρικού κτιρίου του αναζητούμενου ΠΕΙΙ/ΜΕ/ΥΕ οικισμού, ή την ύπαρξη τάφου ανήκοντος στο αναζητούμενο ΠΕ ΙΙ νεκροταφείο.

7. Γεωφυσική διασκόπηση – διασταύρωση των αποτελεσμάτων

Κατά το διήμερο της 10ης και 11ης Απριλίου 2011 πραγματοποιήθηκε γεωφυσική διασκόπηση για τμήμα μόνο του βορείου πλατώματος, εξαιτίας των εξαιρετικά δυσμενών καιρικών συνθηκών που έτυχε να επικρατήσουν κατά το χρονικό διάστημα που έλαβε χώρα η συγκεκριμένη έρευνα. Η διεξαγωγή των εργασιών της γεωφυσικής διασκόπησης πραγματοποιήθηκε από τον καθηγητή του Πανεπιστημίου του Cagliari της Σαρδηνίας (*Dipartimento Ingegneria del Territorio*) κ. Gaetano Ranieri, με τη συνδρομή των τεχνικών βοηθών του. Εφαρμόστηκαν οι μέθοδοι της *ηλεκτρικής τομογραφίας* (*electric tomography*) και του *γεω-ραντάρ* (*geo-radar*) (Gaviano *et al.* 2000–2001): και οι δύο μέθοδοι έδωσαν υψηλές τιμές στις περιοχές όπου είχαν ανιχνευθεί γραμμικά ίχνη και ίχνη σκιών μικροαναγλύφου μετά την ψηφιακή επεξεργασία και φωτοερμηνεία των τηλεπισκοπικών απεικονίσεων, γεγονός το οποίο ενισχύει την εικασία ύπαρξης στις περιοχές αυτές θαμμένων αρχαιολογικών καταλοίπων.

8. Συμπεράσματα

Συνδυάζοντας τα στοιχεία που προέκυψαν από την εφαρμογή της φωτοερμηνευτικής μεθοδολογίας, την πραγματοποίηση του επίγειου ελέγχου, την υλοποίηση της γεωφυσικής διασκόπησης με τις μεθόδους της ηλεκτρικής τομογραφίας και του γεωραντάρ μπορούμε να θεωρήσουμε εξαιρετικά πολύ πιθανό τα εντοπισθέντα γραμμικά ίχνη και ίχνη σκιών μικροαναγλύφου να υποδεικνύουν θαμμένα αρχαιολογικά κατάλοιπα. Ωστόσο, είναι απαραίτητη η επαλήθευση των πορισμάτων της παρούσης μελέτης και με την ανασκαφική σκαπάνη, με τη διεξαγωγή, σε πρώτη τουλάχιστον φάση, δοκιμαστικών τομών, με προτεραιότητα στην περιοχή του πλατώματος τη διερευνηθείσα και με τη μέθοδο της γεωφυσικής διασκόπησης.

Η προτεινόμενη μεθοδολογία, εφόσον είναι δυνατή η συγκέντρωση τηλεπισκοπικών απεικονίσεων για την εκάστοτε περιοχή μελέτης:

-Δεν διαταράσσει το περιβάλλον της περιοχής όπου εφαρμόζεται.

-Είναι εξαιρετικά οικονομική.

-Είναι εξαιρετικά γρήγορη.

-Δεν απαιτείται η επίσκεψη των ερευνητών στον υπό μελέτη χώρο (για τις περιπτώσεις δυσπρόσιτων περιοχών), δεδομένου ότι μπορεί να ολοκληρωθεί μόνο εργαστηριακά. Στις περιπτώσεις βέβαια κατά τις οποίες δεν είναι εφικτή η επί τόπου διασταύρωση των εργαστηριακών αποτελεσμάτων, μένει πάντα ανοιχτό το θέμα ελέγχου του βαθμού αξιοπιστίας τους και με άλλες μεθόδους.

-Η διεκπεραίωσή της δεν εξαρτάται από την έκδοση άδειας από την εκάστοτε αρμόδια Υπηρεσία, δεδομένου ότι δεν είναι απαραίτητη η επίσκεψη των ερευνητών στον υπό μελέτη χώρο, τουλάχιστον για τα πρώτα βήματα διερεύνησης του αρχαιολογικού προφίλ της μελετώμενης κάθε φορά περιοχής.

-Μπορεί να συμβάλει στη συμπλήρωση του ψηφιδωτού του αρχαιολογικού πορτραίτου της ευρύτερης περιοχής που σχετίζεται με το διερευνώμενο σημείο, προφυλάσσοντάς την έτσι από ανεξέλεγκτες ανθρώπινες επεμβάσεις (ιδιωτικά ή δημόσια έργα).

-Είναι, επίσης, δυνατόν να εφαρμόζεται διερευνητικά, πριν την ολοκλήρωση μιας αγοραπωλησίας (ιδιωτικής ή δημόσιας) προκειμένου να καθίσταται γνωστή, έως ένα βαθμό, η κατάσταση κάτω από την επιφάνεια του εδάφους (όσον αφορά σε αρχαιολογικά κατάλοιπα), τουλάχιστον ως ένα πρώτο βήμα ελέγχου, το οποίο ανάλογα με τα πορίσματα που θα προκύψουν θα πυροδοτήσει και τα επόμενα πιθανά. Δημιουργούνται έτσι κάποιες προϋποθέσεις ώστε να περιορίζονται στη συνέχεια, όσο αυτό είναι δυνατό, προβλήματα νομικής φύσεως.

Η ολοκλήρωση των δυνατοτήτων των τηλεπισκοπικών απεικονίσεων για την ανίχνευση μη ανασκαμμένων αρχαιολογικών καταλοίπων ήταν ο στόχος της συγκεκριμένης εργασίας με ένα δυνάμει θετικό αποτέλεσμα, προκειμένου αυτά να διασωθούν από πιθανή καταστροφή τους λόγω ιδιωτικών ή δημόσιων έργων ή περιπτώσεων αρχαιοκαπηλείας, να ενταχθούν σε ένα ευρύτερο δίκτυο αρχαιολογικών θέσεων αλληλο-συσχετιζομένων, και να αποτυπωθεί έτσι, με μη παρεμβατικό και καταστροφικό για το μικροπεριβάλλον της εκάστοτε περιοχής, το αρχαιολογικό πορτραίτο ενός ευρύτερου χώρου, συμβάλλοντας παράλληλα σε μια πιο ευέλικτη λειτουργία του κρατικού μηχανισμού όσον αφορά στο σχεδιασμό, οργάνωση και χρηματοδότηση αρχαιολογικών αποστολών.

Στο σημείο αυτό αξίζει να αναφέρουμε το άρθρο 32 του υφιστάμενου αρχαιολογικού νόμου στην Ελλάδα: "Ως αρχαιολογική έρευνα πεδίου νοείται η έρευνα του εδάφους, του υπεδάφους, του βυθού της θάλασσας ή του πυθμένα των λιμνών ή ποταμών που έχει ως σκοπό τον εντοπισμό ή την αποκάλυψη αρχαίων μνημείων, είτε αυτή συνίσταται σε ανασκαφή, χερσαία ή ενάλια, είτε σε επιφανειακή έρευνα είτε σε επιστημονική έρευνα που διενεργείται με γεωφυσικές ή άλλες μεθόδους". Καθίσταται λοιπόν σαφής η βαρύτητα που αποκτά η ανάπτυξη μιας μεθοδολογίας, όπως αυτής της παρούσας μελέτης, προκειμένου να διασφαλισθεί περισσότερο η προστασία μη ανασκαμμένων αρχαιολογικών χώρων.

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Recording and Automated Methods for Assisting Excavation and Laboratory Work

ADDITIVE ARCHAEOLOGY: THE SPIRIT OF VIRTUAL ARCHAEOLOGY REPRINTED

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Περίληψη/ Abstract

Τη δεκαετία του 1980, οι αρχαιολόγοι υιοθετούσαν με θέρμη τα ραγδαία αναπτυσσόμενα πεδία της μοντελοποίησης μέσω υπολογιστών, των υπερκειμένων και της οπτικοποίησης ως οχήματα για την εξερεύνηση των αρχαιολογικών δεδομένων. Μπροστά στις νέες αυτές συνθήκες επινοήθηκε ο όρος 'εικονική αρχαιολογία'. Ο όρος αρχικά προοριζόταν για να περιγράψει μια πολυδιάστατη προσέγγιση για τη μοντελοποίηση των φυσικών κατασκευών και των διαδικασιών της αρχαιολογίας του πεδίου, μέσω της οποίας η τεχνολογία θα μπορούσε να αξιοποιηθεί έτσι ώστε να επιτύχει νέους τρόπους εμπειρίας, καταγραφής και ερμηνείας των πρωτογενών αρχαιολογικών δεδομένων και διαδικασιών. Παρά τις αρχικές εκτιμήσεις ότι η 'εικονική αρχαιολογία' θα μπορούσε να επιφέρει τις προσδοκώμενες αλλαγές στην έρευνα πεδίου, εντούτοις δεν τα κατάφερε. Καθώς πλέον το αρχαιολογικό υλικό είναι κυρίως ψηφιακό, οι τομές, οι κατόψεις, τα σχέδια και οι φωτογραφίες αποτελούν αναπαραγωγή των αναλογικών μεθόδων που προηγήθηκαν. Η διατήρηση των συμβάσεων των αναλογικών μεθόδων καθίσταται ολοένα και περισσότερο αναχρονιστική με την επικράτηση των ψηφιακών τεχνολογιών και κυρίως με τις εξελίξεις του 21ου αιώνα στο πεδίο της 'προσθετικής κατασκευής', που διαδόθηκε χάρη στους τρισδιάστατους εκτυπωτές, και δύναται να φέρει τον κόσμο της εικονικής αρχαιολογίας πιο κοντά με την υλικότητα της παραδοσιακής αρχαιολογίας. Το άρθρο αυτό υποδεικνύει πως παρά τις τεχνολογικές εξελίξεις, μεγάλο μέρος της θεωρητικής υποδομής στην οποία στηρίζεται η εικονική αρχαιολογία παραμένει επίκαιρο, τρεις και πλέον δεκαετίες μετά την αρχική χρήση του όρου. Μέσα από την ανάλυση των ταχέως αναπτυσσόμενων τεχνολογιών προσθετικής κατασκευής, το παρόν άρθρο θα δείξει πως είναι αναγκαίο να προχωρήσουμε πέρα από μια παθητική προσπάθεια προσαρμογής των τεχνολογιών με σκοπό να αναπτύξουμε αυθεντικές αρχαιολογικές προσεγγίσεις στην τεχνολογία.

Archaeologists in the 1980s were embracing wholeheartedly the rapidly expanding field of computer modelling, hypertext and visualisation as vehicles for data exploration. Against this backdrop 'virtual archaeology' was conceived. The term was originally intended to describe a multi-dimensional approach to the modelling of the physical structures and processes of field archaeology. It described some ways in which technology could be harnessed in order to achieve new ways of experiencing, documenting, interpreting and annotating primary archaeological materials and processes. Despite its initial promise, virtual archaeology failed to have the impact upon archaeological fieldwork which might have been expected. While the archaeological record is now primarily digital, its sections, plans, drawings and photographs are facsimiles of the analogue technologies which preceded them. This retention of analogue conventions is increasingly out of step with the general prevalence of digital technologies and especially 21st century advances in 'additive manufacturing', popularised through 3D printers, which could bring the world of virtual archaeology into closer alignment with the material one. This paper will set out to demonstrate that in spite of technological developments much of the theoretical infrastructure which underpinned virtual archaeology remains as relevant today as it was when the term was first conceived. Through an analysis of rapidly developing additive manufacturing technology, this paper will demonstrate the need to move beyond passive technological appropriation and towards the development of authentically archaeological approaches to technology.

Keywords: virtual archaeology, additive manufacturing, 3D printing, grand challenge

Introduction

Field archaeology, specifically excavations, to some people might seem, not without reason, to represent some kind of externalisation of an anarchic, destructive, drive in the archaeological psyche. Excavators in creating one kind of archaeological record effectively devours, and efficiently effaces, the original, 'proper', archaeological traces or residues from which the record is censored, and an archive created. Following Jacques Derrida (1996), this then becomes the place where things begin, the new starting point, the nexus of a new reality, where impressions collected while 'digging' become reality, embedded in the self-replicating topology of the archive. Many other potential realities become lost in a fog of institutionally induced amnesia, where all the selections and decisions by the diggers, supervisors and specialists that brought the excavation directors or report writers to this point along the path are largely forgotten, with other voices being muted, and nuanced narratives deflected into the margins.

1. The Origins of Virtual Archaeology

Four principal factors lead to the conception of virtual archaeology in 1990 (Fig. 1). The initial factor was the *Rescue* and *Salvage* archaeology lobbies in UK and North America which over the previous decades had successfully built a *polluter pays* platform by positioning archaeological remains as priceless, irreplaceable resources under threat. Public outcry about the treatment of several high profile archaeological remains had helped precipitate PPG 16 in the UK. Henceforth, developers in England and Wales were held responsible for determining the archaeological impact of development and to provide mitigation, or protection (McGill 1995). If the remains could not be preserved *in situ,* a fastidious, empiricist archaeology, couched in the trappings of positivist science, afforded the solution known as 'preservation by record'; in fact a set of *pre-structured* archives (Reilly 1992, 163, 170) Archaeology, however, particularly fieldwork, and especially excavation, is a craft discipline. The use of tools, be they material, digital or conceptual, is the crucial factor and their influence on the direction of work done is not merely important but frequently decisive. Put simply, new tools make possible the production of entirely new sorts of data, information, interpretation and, ultimately, archaeology (Lucas 2012, Reilly 1985, Reilly & Rahtz 1992a). In the 1980's archaeologists were embracing the rapidly expanding field of computer modelling and visualisation as vehicles for archaeological data exploration. Hypertext was also a very exciting emerging technology, and a number of innovative simulation studies evaluating survey methods and data had been published (e.g., Fletcher & Spicer 1988, Scollar 1969). Unfortunately, the inertia of pre-existing traditions of field recording practice and their epistemological assumptions had already largely been re-assimilated with little critical attention and now, propped-up by computerised scaffolding, were affixed with a veneer of self-evidence.

At that point in time an excavation was described as an 'unrepeatable experiment' (Barker 1993, 1). The challenge it seemed then was to overcome this perceived methodological oversight by demonstrating that the decisions on how to explore the raw archaeology would have a decisive influence on the reported outcomes. This could only be done with something that could be taken to pieces and explored repeatedly in many different ways.

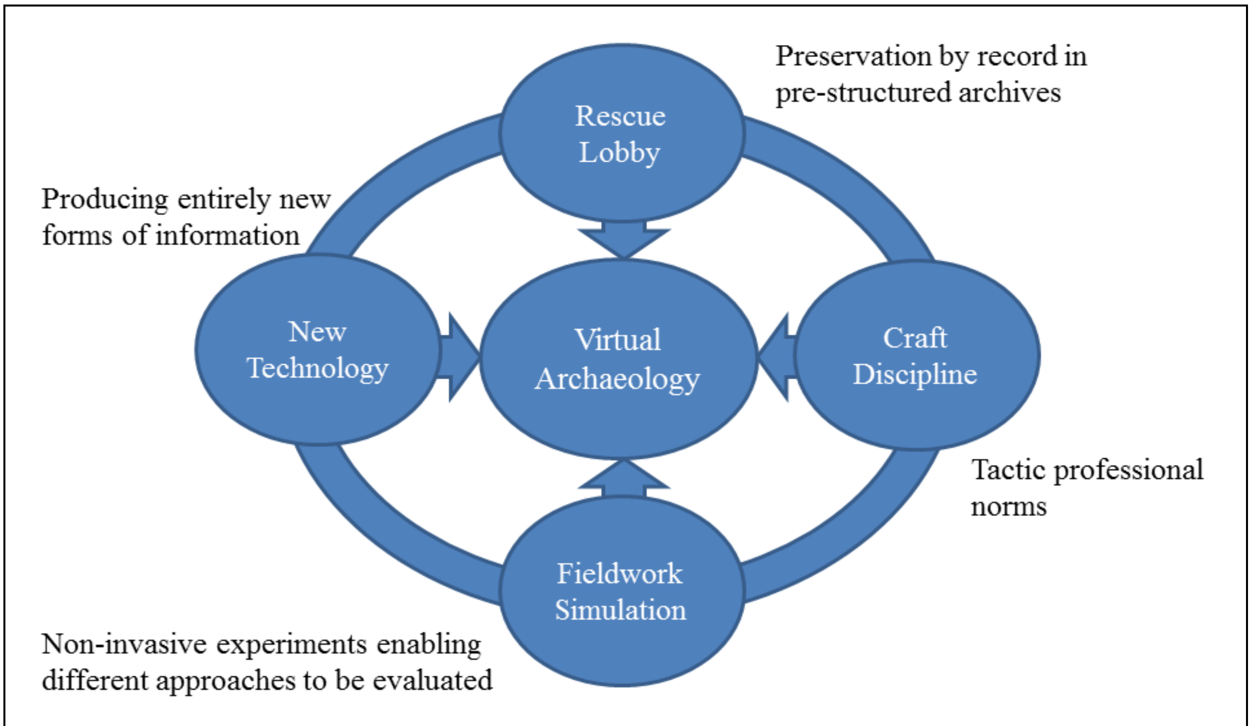

Figure 1 The origins of Virtual Archaeology.

The impasse was broken by invoking the concept of virtuality (Reilly 1991). Virtual archaeology described the way in which technology could be harnessed in order to achieve new ways of documenting, interpreting and annotating primary archaeological materials and processes, and invited practitioners to explore the interplay between digital and conventional archaeological practice.

An animated 3D computer model of a hypothetical excavation presented at CAA in 1990 (Reilly 2013) was the first example of applying solid modelling technology as virtual archaeology (Reilly 1991, 133–136). The intent was to incite, using the terminology of Bourdieu (1977), an 'epistemological rupture' in conventional archaeological recording and representation of excavation data by demonstrating the arbitrariness of conventions, such as sectional or plan drawings and photographs, whilst demonstrating the possibility of developing new, radical, recording strategies, the relative advantages of which could be examined, discussed and evaluated in a non-destructive disciplinary context.

In other words virtual archaeology was not only about 'what was' and 'what is', it was meant also to be a generative concept allowing for creativity and improvisation including 'what might come to be'.

2. The Relevance of Virtual Archaeology Today

During the period since its first articulation virtual archaeology has become predominantly associated with the use of 3D computer graphics within archaeological research. This is an association which has been established and reinforced through a long series of publications (Gutierrez *et al.* 2007, Pletinckx 2009, Wittur 2013). There can be little doubt that these activities form a part of what might be considered virtual archaeology but they do not comfortably define the limits of the original term.

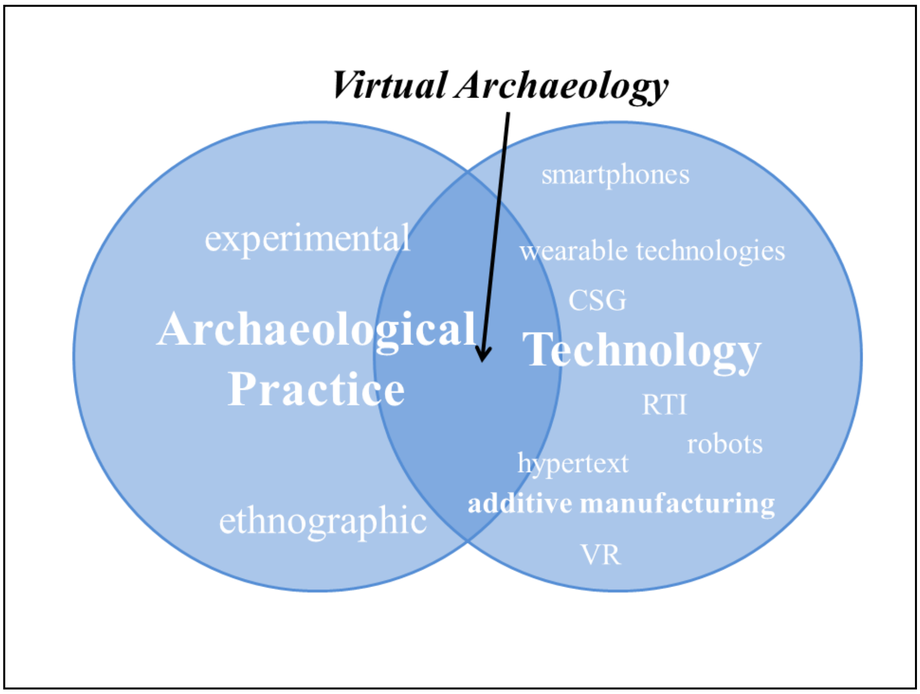

Figure 2 The spirit of virtual archaeology renders explicit the dynamic relationship between archaeological practice and technology.

Virtual archaeology, as first articulated, described the use of digital technologies as tools for mediating and engaging with conventional (analogue) archaeological processes. This definition was broad and potentially encompassed a wide range of technologies and processes. It should be made clear that the term 'virtual reality' was deliberately avoided and the importance of the non-graphical aspects of 3D computer modelling was highlighted (Reilly 1991, 1992). That an emphasis was placed on computer graphics is not surprising; the 1990s and 2000s saw rapid developments in this area accompanied by the falling costs of technology. However, reifying virtual archaeology into any specific technology amalgam is to miss the point.

The notion behind virtual archaeology was, and remains, useful for emphasising the intersection between technology and archaeological practice. For want of a better term, the *spirit of virtual archaeology* describes something which is inherently changeable, and which depends on the availability of technology and its potential utility within a specific situation be it in field or laboratory conditions (Fig. 2). Thus it was entirely natural that early papers which used the term *virtual archaeology* frequently dealt with the applications of 3D computer graphics, databases and hypertext. The specific technological emphasis says more about the state of technological development than it does about the essential meaning or relevance of the term. What remains of paramount importance is the need to focus on the practice of adopting technology as well as the technology itself. The ubiquity of digital devices within contemporary archaeological practice coupled with the proliferation of software with potential archaeological applications means that this need is greater than ever.

Recent technological developments have led to a proliferation of devices and software which augment, and often enhance, the human experience of the world. Consider, for example, wearable technology, the ubiquity of increasingly powerful smartphones, or the development of 3D printing. These technologies do not immerse but rather they augment. They allow the user to engage with the material world in tandem with digital technology. They are authentically tactile and blended with the physical world, offering renewed sensorial prominence and perhaps more cognitive depth through material engagement. Such technologies require a model of virtual archaeology which could not have been foreseen twenty years ago. However, the essential need to experiment with the use of technology, to play with it and to find new archaeological applications remains constant.

3. Virtual Archaeology Remains Useful

Many discussions regarding the epistemological status of virtual archaeology over the last two decades can be seen as an expression of a deeper anxiety discourse affecting *archaeological computing* in general (Ryan 2001, Frischer *et al.* 2002, Forte & Pescarin 2006, Pujol 2008, Llobera 2011, Huggett 2013, Forte 2014). Unfortunately, virtual archaeology became a contentious term in a way that other terms such as *archaeological computing* did not. This issue can be largely attributed to the fact that virtual archaeology became associated with a specific technology and a particular conception of how that technology might be used within archaeological practice. In fact virtual archaeology has suffered a similar fate to many other things which incorporated the word ‘virtual’, virtual reality being the prime example. This phenomenon is well documented elsewhere in the humanities, where J Stern (2003) has shown how the language of technology, and the misuse of this language, has been used to sell specific assumptions (academic and ideological) relating to technology. The challenge set by Sterne is to find a means of meaningfully appropriating new technology; to develop new conceptions of technology which are shaped by the intellectual themes and methodologies of our discipline (Sterne 2003, 370).

In the remainder of this paper we will draw on one contemporary technology: *additive manufacturing.* This potentially disruptive technology prompts us to re-engage with some of the core concepts of virtual archaeology, emphasising the fluidity of the term and the continued relevance of the conceptual framework which underpinned its initial use. The case study of additive manufacturing helps to demonstrate that beyond its association with specific technologies the *spirit of virtual archaeology* provides a mechanism for negotiating the use of any technology in archaeological practice.

4. The Spirit of Virtual Archaeology Re-Engaged

One popular example of additive manufacturing, known variously as consumer 3D printing, and rapid prototyping, is experiencing a great deal of hype at the moment. However, additive manufacturing, which, has been around longer than virtual archaeology, encompasses a set of far more mature technologies that have long since passed over the peak of inflated expectations, through the trough of disillusionment, and are steadily advancing up the slope of enlightenment to the stable plateau of productivity, according industry analysts (Gartner 2013).

At a very high level, the huge array of available additive manufacturing technologies can be loosely classified into three groupings. (For a full treatment see Lipson & Kurmar 2013). Selective extrusive printers in essence squirt, squeeze or spray pastes or powders through nozzles, syringes and funnels of all sizes to build up objects by depositing materials in layers. Selective binding printers by contrast, fuse, bind or glue materials together, again in a layers. The aforementioned technologies can, in one sense, be seen as producing analogue printing or additive manufacturing outputs using digital controllers. Currently at the cutting edge is true digital assembly using pre-manufactured physical objects. We can think of them as Lego blocks. However, precise assembly of billions of small physical voxels made in different and multiple materials remains a huge computational and fabrication challenge. Of course, hybrids, deploying multiple *print heads*, deploying various different fabrication methods, could also be configured.

Lipson and Kurmar (2013, 265) summarise the evolution of additive manufacturing as three episodes of gaining control over physical matter*;* control over geometry, composition, and behaviour.

First is an unprecedented control over the geometry, or shape*,* of objects. 3D printers can already fabricate objects of almost any material in any shape. Next is control over the composition of matter. We have already entered into this new episode where we go beyond just shaping external geometries to shaping the internal structure of materials with unprecedented fidelity, with the possibility of printing multiple materials including 'entangled components' which can be co-fabricated simultaneously. The final stage is control over the behaviour of materials, where they envisage programmable digital materials – made of discrete, discontinuous units – which are designed to function in a desired way, such as spongy, transparent, rhinoceros-shaped, in shades of grey and blue – perhaps even embedded with nano devices. Voxel-based printing affords the notion of different types of voxels (Hiller & Lipson 2009). Imagine, if you will, a library of archaeologically-defined material voxel types.

Control over *shape* provides a bridge between existing 3D modelling formats and the ability to repurpose them as 3D printed physical objects. Existing point clouds, terrain and solid models, indeed any system that can output STL format files can be 3D printed. By way of example, a 3D-printed map of the cone, crater, and summit of Mount St. Helens, Washington, USA, is available on Shapeways.com in three sizes (e.g., TinyMtn 2014), various other terrain models have been extracted from GIS systems for 3D printouts in South Africa (Agrawal *et al.* 2006), and geologists have 3D printed a stack of geology (i.e., stratigraphy) from north eastern Germany (Loewe *et al*. 2013). Although all these examples produce solid objects made in a single material, with the same density throughout, they nevertheless communicate in a very tangible fashion.

Makers print all kinds of materials: from bread dough, chocolate, and other food-based materials with their pronounced olfactory characteristics (which, incidentally, introduces another cross-sensory modality into the mix), to gypsum, sand, soil, terracotta, metal alloys, plastics and polymers. At a somewhat higher level of technological sophistication, and, commensurately funding, modern industrial additive manufacturing technologies span a wide spectrum of applications across a very broader range of scales: from bioprinting living ink; replacement body parts and prosthetics; manufacturing textiles; ceramics; glassware; jewellery; furniture; weapons; vehicle components: and innumerable parts and fixtures, including 3D printer components (Lipson & Melba 2013). Crucially, they can also combine *multiple entangled materials* (e.g., Vaezi *et al*. 2013, Vidimče *et al*. 2013).

Let us, as it were, step back and open the aperture of the nozzle, to demonstrate some more examples at a much larger scale and, perhaps, further afield. The potential of additive manufacturing, primarily in the form of 3D printing and rapid prototyping for archaeology and related disciplines is well established. For example, Midwest Studios 3D printed a highly detailed architectural model, for a new Carmelite foundation, designed as a classic French gothic monastery, including flying buttresses, for a growing community in Wyoming, USA, using the architect's (McCrery 2014) CAD files. In Europe, Swiss architects (Hansmeyer & Dillenburger 2014) created and 3D printed an ultra-modern, gothic-like, human-scale, immersive space dubbed the 'Digital Grotesque'. This room-like structure was assembled from 64 massive separate printed sandstone-like parts, containing 260 million surfaces printed at a resolution of a tenth of a millimetre. The 11-ton room took a month to print but only a day to assemble. Elsewhere, the European Space Agency and architects Foster+Partners are exploring the feasibility of building future moon-bases using fabricators exploiting local materials (i.e., regolith or lunar soil). Of course, at the moment, these projects require the use of terrestrial simulants, in other words materials with the same necessary material properties (ESA 2014).

Shifting the meaning of scale somewhat, 3D printing is already causing fundamental changes to our interactions with the finds record and other archaeological assemblages. The Smithsonian museum, for example, has embarked on the ambitious X3D project, which aims to digitalise all 137 million iconic items in its collection, and make them available for 3D printing anywhere in the world. In so doing, we should note, they are also making them available for transcultural discourses within *ethnographic archaeologies*, in the sense of Castañeda and Mathews (2008). Nowadays, virtual museums allow anyone to download and 3D print 'your own museum' (e.g., Lincoln 3D Scans 2014). Scholars have been sharing 3D printed artefacts for great academic profit for some while already.

Cuneiform tablets are the world's oldest known writing system. Older still are bullae, a form of Mesopotamian record-keeping technology in which accounting tokens were sealed inside hollow clay envelopes. Intact sealed bullae are extremely rare. Export of these priceless artefacts from their modern countries of origin (or discovery) and between the few existing major collections is, unsurprisingly, restricted. Nevertheless, specialists all over the world want to examine every minute detail of the tiny, fine characters, but photographs and drawings are generally regarded as inadequate transcription. Accessing the insides of the bullae is only conceivable using non-invasive methods (Marko 2014). An approach currently being developed combines CT scanning and 3D printing capabilities to enable detailed visual and tactile examinations with minimal handling so that originals can be safeguarded (Kaelin 2013).

These new objects may be (re)printed in different materials at different scales and the bullae facsimiles can be broken open to reveal sealed tokens within their interiors, and thereby made available for study without damaging the original artefacts. Such virtual artefacts, are easy to export electronically and download anywhere, rematerialised in any multivalent, transcultural space. Another form of additive manufacturing was employed by researchers in Wales to reverse engineer the construction of a medieval ship. The use of this technology not only produced an accurate geometric model to assist the reconstruction of a 15th century ship found in the River Usk, it also demonstrated how material-characteristics can potentially be controlled to contribute to a better understanding of the original artefact's construction than is possible within traditional approaches (Soe *et al.* 2012).

5. Towards an Additive Archaeology

Let us now become more speculative, more aspirational, and explore some facets of additive manufacturing pertaining to materialisations of virtual archaeologies that might come to be.

As additive manufacturing evolved from producing primarily single-material, homogenous shapes to producing multi-material geometries in full colour with functionally graded materials and microstructures, it created the need for a standard interchange file format that could support these powerful new features. The response was the Additive Manufacturing File format (AMF), an open standard for describing objects for additive manufacturing processes such as 3D printing (AMF ASTM 2014). What is striking about the AMF format is that it encapsulates the typical recording sheet used on a modern archaeological excavation (Fig. 3), but does so in much finer *spatio-compositional*, that is in both macro-morphological and micro-morphological, detail.

If we did recast our recording method to generate contexts described in an AMF-like format, we suggest that archaeology would be a step closer to aligning the virtual and physical worlds, and a step closer towards the possibility of rematerialising archaeological *entities* found in the field.

What is to stop us from recording our excavations in such a way so as they can be refabricated? Current methods are clearly deficient. Here, by the way, we are not suggesting that all excavation should be 3D printed. We submit that if we recorded in such a way that we could rematerialise, or refabricate, our excavations in 3D then we would have improved substantively our practice.

Some will argue that current procedures are adequate for current needs. We counter, that in a uniquely destructive discipline, are we not ethically obliged to strive for superior recording practices?

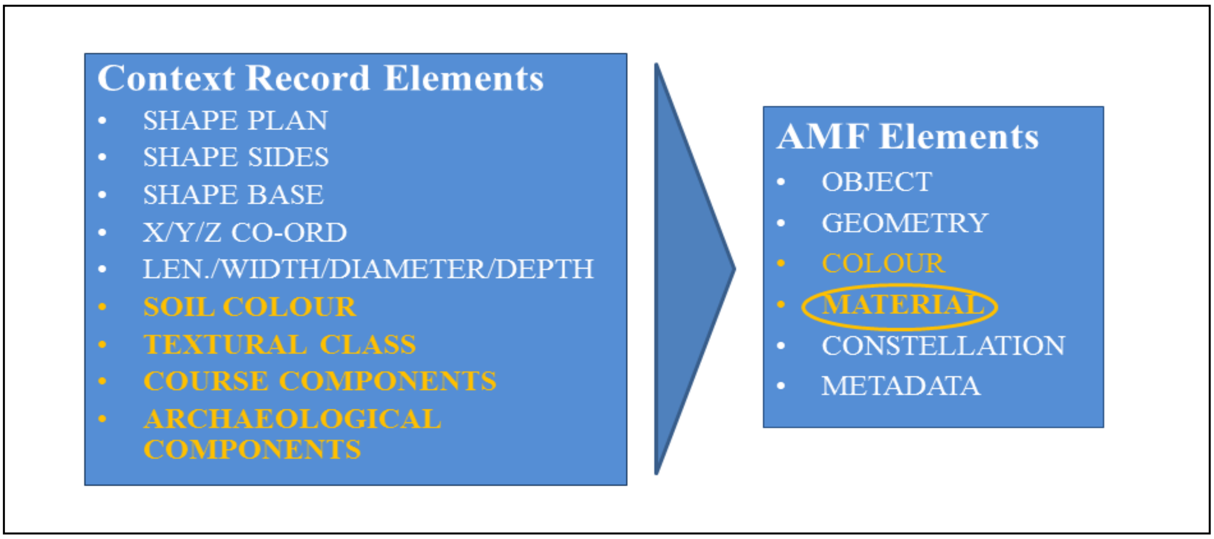

Figure 3 Materialisation: the AMF file format encapsulates all the elements of an archaeological context record making possible a closer alignment between virtual and physical worlds.

Glimpses of *additive archaeology***,** which is just one particular echo of the spirit of virtual archaeology materialised through additive manufacturing, can be discerned already in the work of soil scientists and archaeologists conducting virtual excavations involving both scientific visualisations and 3D printing. For example, using a combination of Computed Tomography (CT) and 3D printing, soil scientists now have the ability to explore something so intricate and detailed as the structure of soil, close up, and set up multiple experimental investigations (Otten & Falconer 2014). Similarly, archaeologists can now disaggregate and re-aggregate non-intrusively a coin hoard found in one of two pots near Selby in the north of England. The CT data, which can be resolved down to two microns, were processed to produce an animation (Miles & Cox 2013) and extract 3D prints of some of the coins (Miles, 2012, Miles *et al.* 2014).

Conclusion

Additive manufacturing is just one technology enabling the *spirit of virtual archaeology* to generate new challenges to transform archaeological practice positively. Printing artefacts, monuments and cultural landscapes is established technologically and is already starting to disrupt both transcultural and disciplinary discourses and narratives as direct access these *e-cultural entities* by almost anyone, almost anywhere, to materialise them in any transcultural space, effectively disintermediates the opinions, interpretations and 'authority' of archaeologists and cultural resource managers. The implications of the above abbreviated, and much truncated, thesis for archaeology are immense. Releasing the spirit of virtual archaeology will add a technological nuance to the debate on the ontology of archaeology (Hamilakis 2014, 128).

We specifically contend that additive manufacturing provides a credible challenge to traditional archaeological practices (e.g., in recording). With this in mind, we want to respond to J Huggett's (2013) call for disciplinary 'grand challenges' for the next generation of archaeologists, so as to provide a catalyst for renewed innovation, strength of purpose, and direction in archaeological computing. We propose a disciplinary grand challenge to fabricate an excavation. That is an excavation rematerialised so as to be geometrically and compositionally accurate, whereby the curious can explore iteratively, reflexively, and comprehensively, the disaggregation and reassembly of archaeological entities encountered through archaeological intervention in such a manner as to engender a constant, multivalent, hermeneutic cycle between analysis and synthesis. We envisage that in striving to meet this challenge, the discipline will establish elements of an exemplary platform for strategic innovation, affording the development, and structured introduction, of innovative and distinctly archaeological approaches.

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PHOTOGRAMMETRY AS A TOOL FOR ARCHITECTURAL ANALYSIS: THE DIGITAL ARCHITECTURE PROJECT AT OLYMPIA

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Περίληψη/ Abstract

Το Digital Architecture Project (DAP) δημιουργεί μοντέλα τριών διαστάσεων και ψηφιακές αναπαραστάσεις Αρχαϊκών ελληνικών ναών. Πρόσφατη φωτογραμμετρική έρευνα του ναού της Ήρας στην Ολυμπία, του αρχαιότερου και καλύτερα διατηρημένου οικοδόμηματος Δωρικού ρυθμού στην Ελλάδα, οδήγησε στην κατασκευή ένος τριδιάστατου μοντέλου υψηλής ανάλυσης για το οικοδόμημα (διαστάσεων 20x50 μ περίπου). Η γραμμική ακρίβεια μέτρησης έχει καθοριστεί στο ± 1 χλστ. σε τοπικό επίπεδο, και στα ± 10 χλστ. σε παγκόσμιο επίπεδο (95% CI). Η ανάλυση των οπτικοποιήσεων έχει ήδη δώσει σημαντικά στοιχεία για την αρχιτεκτονική ιστορία του ναού. Για τη διαχείριση του μεγάλου όγκου των δεδομένων, τα μοντέλα έχουν αποδοθεί σε επίπεδα δύο διαστάσεων σε αντιστοιχία με τις συμβατικές κατόψεις και τομές. Το DAP προτείνει ένα ψηφιακό μουσείο για τη διάδοση αυτών των δεδομένων.

The *Digital Architecture Project* (DAP) produces 3D models and reconstructed visualizations of archaic Greek temples. Its recent photogrammetric survey of the temple of Hera at Olympia, the earliest well-preserved Doric structure in Greece, resulted in a high-resolution 3D model for the ca. 20x50 m structure. The linear measurement accuracy has been determined to be as high as ± 1 mm locally, and ± 10 mm globally (95% CI). The analysis of the visualizations has already provided valuable insight into the temple's architectural history. In order to manage the large amount of data, the models have been rendered in 2D layers corresponding to conventional state plans and elevations. The DAP proposes a virtual museum for disseminating this resource.

Keywords: Olympia, architecture, photogrammetry, accuracy, 3D recording, virtual museum

Introduction

Photogrammetry (PG), the process by which 3D coordinates are measured from a camera, has the potential to revolutionize how we study and document antiquity. While the principles have long been applied for aerial survey, only in the 1980s was 'close-range' PG successfully adapted for precise measurement of objects from the ground (Fraser & Brown 1986). With the development of inexpensive digital cameras in the 1990s and software for their calibration, PG has become widespread in many other applications (Luhmann 2010). Although not as reliable as metric cameras, a consumer SLR can still be calibrated for measurement accurate to 0.1 mm over a 2 m object (Fraser & Al-Ajlouni 2006, Rieke-Zapp *et al.* 2009, Zhenzhong *et al.* 2010).

Over the past 15 years, researchers engaged with cultural heritage (CH) have explored the potential applications of close-range PG (Cignoni & Scopigno 2008, Doneus *et al.* 2011, Kersten & Lindstaedt 2012, Pavlidis *et al.* 2007). Many CH projects have used PG to extract coordinates for CAD modelling, typically at the scale of a building or a larger complex, such as a castle. With commercial software like PhotoModeler (© EOS Systems), cameras were calibrated by alignment to control points so that new features could be measured by manually marking them on several images. Because this process is time-consuming, the network of extracted points was typically limited to diagnostic features, which can then be imported into a CAD interface for building an idealized 3D surface model (e.g. Arias *et al.* 2007, Styliadis 2007, Yilmaz *et al.* 2008). At first, close-range PG found a niche as a proxy or supplement for time-of-flight laser systems, especially a Total Station (TS) (e.g. Sahin *et al.* 2012, Yastikli 2007). Unlike the high accuracies attained in controlled tests of PG, many of these CAD-oriented CH projects have reported significant levels of error, with 2-10 cm inaccuracies common in field reports. The focus on measuring coordinates for idealized CAD modelling has meant that the preponderance of CH projects used PG for publicity and education, its implementation being too unreliable and time-consuming for finer analysis.

The situation has changed radically over the past five years. Modern PG software has been enhanced by the incorporation of computer-vision algorithms that automatically match features – a process variously termed Multi-Image PG, Image-Based Modelling, or Structure from Motion (Cignoni & Scopigno 2008, Luhmann 2010, Vergauwen & Van Gool 2006), and which I will refer to as 'automated PG' in this paper. Software automation has been applied throughout the procedure, from the initial stage of camera alignment to the subsequent extraction of a point-cloud interpolated from automatically matched points. With automation, PG really begins to shine: rather than requiring a full day for an operator to measure a few hundred points manually, automated software can reconstruct millions of features within hours or even minutes. With the increases of processor power and RAM capacity in modern computers, detailed 3D reconstruction can be obtained even with a laptop. The software can rapidly produce clean 3D surface meshes with high-resolution photographic textures, making PG an increasingly appealing alternative to laser-scanning (e.g. Koutsoudis *et al.* 2013, McCarthy 2014).

Still, the potential for automated PG demonstrated in the laboratory has yet to be fully realized in practice. While errors below 1 mm have been established in controlled conditions (Jennings and Black 2012, Koutsoudis *et al.* 2013, Remondino *et al.* 2009), measurement mistakes on the order of 5-10 cm are typical in automated PG projects at buildings and sites (Bhatla *et al.* 2012, Dai and Lu 2010, Doneus *et al.* 2011, Klein *el al.* 2012, Remondino *et al.* 2012, Sahin *et al.* 2012). A standard error of about 1 cm has been reported in a few applications at the trench- and building-scale, implying mistakes in the 1-5 cm range would occur in these datasets (De Reu *et al.* 2013, De Reu *et al.* 2014, Dellepiane *et al.* 2013, Kertsen & Lindstaedt 2012, Koutsoudis *et al.* 2014, Olson *et al.* 2013, Riveiro *et al.* 2011).

As the software becomes increasingly powerful, automated PG promises to surpass illustration by hand and laser-scanning as the standard recording technique in the field and museum. However, the quality and accuracy of PG under the demanding conditions of the field, the potential research value of the resulting 3D meshes, and how digital 3D data are best published have yet to be established. I consider each of these questions in light of my recent implementation of PG at Olympia. This paper focuses on mesh quality, but it also considers PG as an analytical tool and describes plans for publishing these 3D data in a virtual museum.

1. The Digital Architecture Project

The *Digital Architecture Project* (DAP) exploits the power of automated PG for field recording and publication of ancient architecture. In service of its broader investigation into the emergence of the Doric style in the Archaic Period, the DAP is creating 3D models of the current state and reconstruction of temples from Mainland Greece and Italy. The high-resolution 'state model' for each ancient building is intended to support architectural analysis, by superseding the kinds of 2D plans and elevations used in traditional architectural illustration.

The first subject of the DAP is the Temple of Hera at Olympia, chosen for its excellent preservation, early date (*c.* 590 B.C.), and importance to the development of early Doric architecture (e.g. Dörpfeld & Schleif 1935). Initial fieldwork was completed in July 2013, resulting in the 3D models presented here. Although fieldwork will continue, the recording of the building is already largely complete.

Objectives: The recording system developed for Olympia was designed to test the effectiveness of PG under difficult field conditions. A major question is whether PG can supersede manual illustration, which continues to be the standard approach to recording ancient architecture. There are five aspects to consider (compare to Pavlidis *et al.* 2007):

(1) Scale: The field methods must be efficient enough to be applied to buildings and large complexes. In addition to the *in situ* remains, the DAP plans eventually to digitize displaced architectural fragments in the museum, but for now the process is only evaluated for a whole building.

(2) Quality: The precision for architectural study and analysis must be as high as for manual recording. Dimensions are published to the nearest mm or cm in most architectural studies, and features down to individual tool marks or joint surfaces are recorded. Thus, PG models need a resolution of 1–2 mm or less, or else fine details will be lost and mm-level measurement will be impossible. The error for manual recording is relatively high, however; at the building scale, manual or TS linear measurement error is at least ± 5–10 mm, and often greater.

(3) Practicality: for widespread adoption, the PG method should be simple enough to be implemented by CH researchers with some technical skills. The equipment must be portable and be able to function even at an active site like Olympia with thousands of visitors every day.

(4) Budget: While 3D modelling for CH has in some cases attracted tens or even hundreds of thousands of dollars in funding – e.g. for laser-scanning significant monuments – minimizing cost is essential for most field projects. Processing time after the fieldwork concludes must also be considered.

(5) End-product: The 3D data should be presented in formats usable by researchers without demanding special technical skills or costly software.

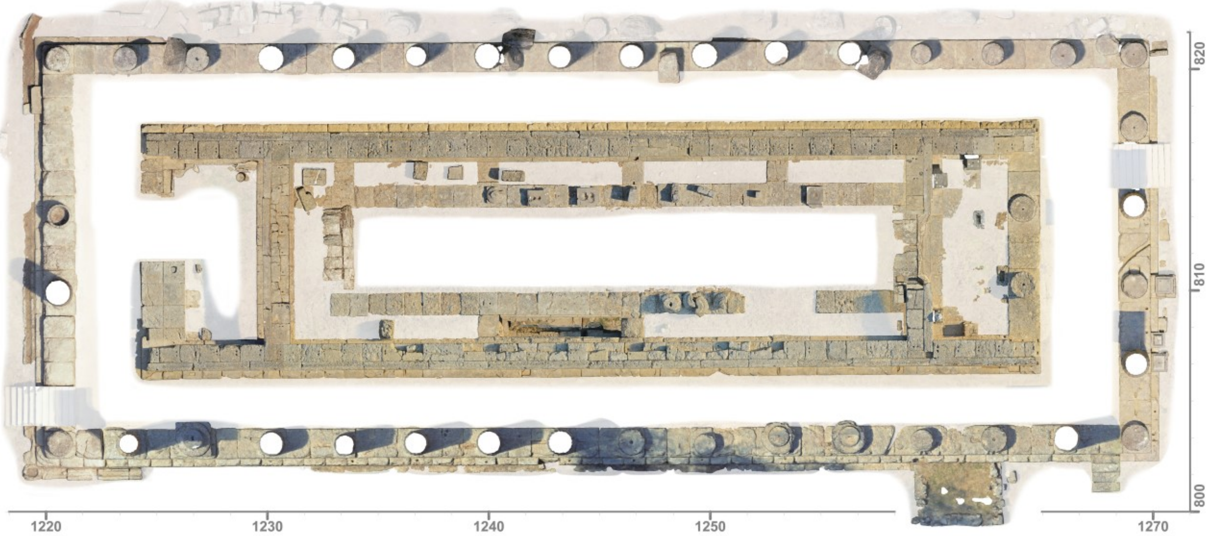

Figure 1 Digital top plan of the Heraion at Olympia (DAP, © 2013 Sapirstein)

2. Photogrammetry at Olympia

Implementation on site: The DAP used a TS for measurement on site, establishing a network of 190 control points in the excavation's grid coordinates. At least 100 points would be necessary for a building as large as the Heraion. A Nikon D800e, a 36.3 Mpx digital camera, equipped with a zoom lens set to 28 mm was used for photography. The 36x24 mm sensor is sharper than other digital SLRs currently available, more than doubling the linear pixel resolution compared to a 12.3Mpx Nikon D5000 also tested on site. The D800e can capture the full dynamic range of light under direct midday sunlight. In comparison, if the D5000 is metered to capture detail in direct sunlight, it loses definition in the shadows, and vice-versa. The D800e sensor reduces the number of photographs required to capture the stone surfaces at a given level of detail, which improves accuracy, increases how much area can be recorded on site, and reduces processing times.

The Heraion is a large structure, but detailed imagery of its stone surfaces is required for architectural study. The temple occupies a roughly 55x25x7 m volume, and the exposed surfaces exceed 1,100 m^2 in area. While it might be possible to photograph the entire structure at once from the air, the resolution would be limited to about 1 cm per pixel—falling short of the desired 1–2 mm resolution (Objective #2). Instead, I took photographs at a distance of 2.0–2.5 m, on the ground or a ladder, for an initial photographic resolution below 0.5 mm per pixel.

Due to the rapidly changing light as the sun moved through the sky, I was limited to no more than a half hour of photography at one time: otherwise the shadows changed too much in orientation and character for the software to locate matching points accurately. Because it was physically impossible to photograph the entire structure this quickly, the job had to be divided into segments. One might document the entire building under the same lighting conditions by shooting only at the same period each day — which would take about two weeks for the Heraion. However, as an architectural historian, I wanted to have raking light cast on the surfaces, which emphasizes tooling and other subtle inflections in the stone texture that are difficult to see in full shadow or direct illumination. For example, I elected to photograph the south and north faces of the cella walls at different times of day so as to record both sides under raking light, even though this required separate batches of photographs. This also allowed me to finish the job more rapidly by photographing segments of the building when optimal lighting was available at various times of day. The whole temple was captured in 17 different groups of photos. Although the software cannot align these groups to one another directly, they are oriented to the same control points. The final imagery blends segments with different lighting conditions, as can be seen in Figure 1.

Processing in the office: Automated PG requires intensive computation to extract dense 3D meshes. The DAP used two laptops with 8GB of RAM and dedicated graphics cards. The commercial software used for PG, Agisoft PhotoScan Pro, is the least expensive of the commercial options with survey capabilities (De Reu *et al.* 2013, Koutsoudis *et al.* 2014, Olson *et al.* 2013, Remondino *et al.* 2012). The program has four primary phases requiring user input. First, one must load a group of photographs into a new project file and calculate the alignment. Although fully automated, the calculation of the camera orientations and calibration took up to three hours for the largest groups of photos (up to 300). Second, one must identify the control points measured with the TS, which at Olympia were nails driven into the ground and marked with a 1 mm dot. While sturdy and easy to measure with the TS, the

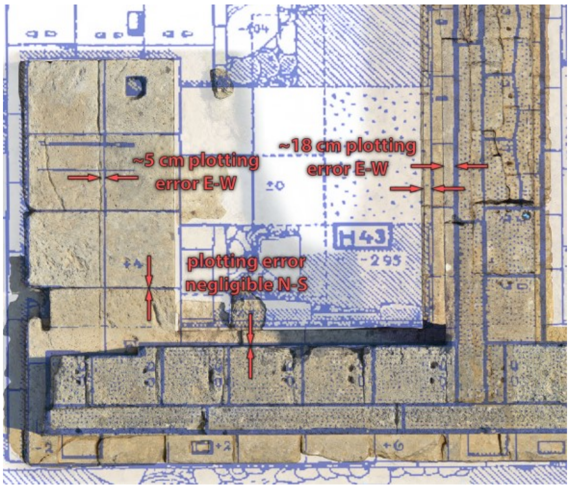

Figure 2 Comparison of the DAP and manual plans at the opisthodomos (Dörpfeld & Schleif 1935, pl. 9)

nails had to be marked manually in the software. The software then calculates a Procrustean fit of the marked PG points to site grid coordinates recorded with the TS. Manually marking points was the most time consuming of the processing stages. While I could finish smaller sets in as little as 30', the largest groups took 2–3 hours. I also made mistakes, necessitating a time-consuming search to discover which incorrectly marked point had thrown off the PG measurement. The third phase is dense surface reconstruction. This requires almost no user input but is the most computationally intensive step. The processing times vary depending on the parameters and RAM capacity, but I limited calculations to about five hours. Fourth, the photographic texture is projected on the resulting 3D mesh. This requires little user input and computes quickly.

The 17 groups of photographs had to be aligned and rendered separately. Although there were 2000 photographs in total, no group had more than 300 images. To save computing time, I used the program's 'Medium' quality settings, which down-samples to 1/4 of the pixels in the original images. The largest sets still had to be subdivided into smaller segments for processing because of RAM limits. In the end, the Heraion was divided into 50 processing segments, each decimated to 4Ma vertices and draped with an 8192x8192 pixel texture. Although the resolution of the 3D geometry is high for sharp features, like corners, small perturbations below about 2 mm, like chisel marks, are blurred in the 3D mesh — whose vertices are spaced 3 mm apart on average. However, the textures have a 1.0 mm pixel resolution and capture finer details even if their 3D geometry has been blurred.

Accuracy: While the precision of this data is high, it is critical to examine its accuracy. Although the error in manual illustrations of ancient architecture is seldom discussed explicitly, a standard error greater than 1 cm can be assumed for drawings plotted by hand at this scale (1:50 or smaller), due to the 5% error in human perception (Eerkens 2000). As can be seen in a comparison of the DAP plan to that published in 1935 (Fig. 2), there are in fact manual plotting errors up to 15–20 cm in some parts of the cella, although in most places these earlier drawings agree within a few cm of the DAP photogrammetric plan. This example demonstrates how the scale of human error can increase massively in areas where the illustrator is less concerned about accuracy. While the photogrammetric process can also make blunders, these are immediately apparent to the human operator and corrected. Nonetheless, the standard error in PG varies greatly depending on the job and must be determined empirically by testing the results against known points. The publications to date of field applications using automated PG have yet to consider the problem of error methodically.

There are several potential sources of error. First, the internal orientation of the 16–35 mm zoom lens used at Olympia is less stable than that of a fixed focal-length lens (Fraser & Al-Ajlouni 2006, Rieke-Zapp *et al.* 2009). Tests suggest measurement accuracy would be improved with a fixed lens, although the effect is minor at the scale of the Heraion. Second, the stone surfaces of the temple are rough, pitted, and covered with lichens, creating high-contrast random textures ideal for automated PG. However, I found that camera misalignments are common at sharp external corners, where it is difficult for the software to identify comparison points across the adjacent perpendicular faces. This was problematic during testing. For the final images, I took extra photographs at corners, which fixes these alignment problems though slows processing. Third, the DAP relies on a TS to survey the network of control points, which has a standard measurement error. With the survey prism, the Leica TCR 407 Power has specifies a σ of 3 mm for distance error, to which must be added at least 1–2 mm error from setup over the base point, and another 2–3 mm from the prism not being exactly over the point being measured. In practice, the TS readings will differ by ca. ± 10 mm from the true point at a 95% confidence interval (CI).

For quantifying error in the DAP models, I distinguish *global* from *local* error. Global error represents the divergence of PG-derived points from true site coordinates, whereas local error represents the internal consistency over shorter segments of the model. Local error was examined by comparing models at the intersection of the north and west cella walls, where there are five separate groups of photographs. A total of 10 meshes with a 0.5 mm texture resolution were generated at different qualities ('Low/Medium' or 'High/Ultra') to test the error contribution of the program settings (Fig. 3). Nine test points on high-contrast features were marked in 2D, and each scan shifted to minimize the

	$\bar{x}$	*n*	σ	RMS
All scans (10)	0.9	78	0.76	1.19
High quality (6)	0.7	43	0.55	0.89
Low quality (4)	1.2	32	0.97	–

Table 1: Local coordinate error (x) in mm, by 2D distance from points 1–9 (Fig. 3)

	n	σ	95% CI	RMS
PG internal error	162	4.2	± 8	4.2
PG vs. TS	162	6.1	± 12	6.1

Table 2: Global measurement error in length (mm)

(Differences)	< 5	5–15	15–25	> 25
Clear features	12	6	–	–
Indistinct	7	4	6	–

Table 3: PG vs. legacy length measurements (mm)

Figure 3 Comparison points, north cella wall

distance from these points, thereby eliminating global error. The errors are summarized in Table 1. Higher quality settings (using 50–100% of the original image pixels) reduced error by 50% relative to lower settings (down-sampling to 12.5–25%); overall the 3D data from Olympia is repeatable within a 95% CI of ± 1 mm. Thus the internal PG alignments appear to be more accurate than the TS measurements. However, error in the control points has introduced minor distortions into the PG camera alignments, so one might attain an even higher local accuracy from more reliable control points.

As for global error, the 10 overlapping scans were shifted by an average of 5 mm (σ = 4.6) for local comparison. A more meaningful approximation of global error, however, is obtained by comparison of the coordinates measured in the TS to those estimated in the PG models. A subset of the 19 control points visible in at least three different PG groups was selected, and the lengths calculated between these points. Altogether 162 lengths could be derived from the PG control points for comparison to the original TS survey. The PG lengths are not entirely independent from those of the TS, but they are from a subset of the 129 points used to position and scale the PG models and thus are the best available test for the error in measuring length — which is key for architectural analysis. Table 2 presents an internal comparison of lengths (relative to control point coordinates averaged from all 17 PG sets), and the PG lengths against those from the TS survey. The former is an underestimate of the standard PG length error, whereas the latter is an overestimate because it disregards the internal accuracy of the PG network relative to the TS survey. The errors are normally distributed, indicating a 95% CI of ca. ± 10 mm for lengths.

These results for global error are corroborated by the comparison of PG lengths of features to measurements from the early 20th century (Dörpfeld & Schleif 1935). These legacy measurements (taken manually with a tape) are published to the nearest cm and so only provide an approximate indication of the PG accuracy in mm. Some features are clear and consistent in width, whereas others are obscured by slight changes in dimension in the feature, either from damage to the stones, or from inconsistencies in the ancient workmanship. As recorded in Table 3, of the 18 clearer features, the PG measurement is indistinguishable from Dörpfeld's in 12 cases, and about 1 cm off in the other 6 cases. As might be predicted, the PG measurements of the 17 less distinct features differ more from the legacy data, but the two sets of measurements are all within 2 cm of one another, with a median discrepancy of 1 cm. Of note is the close correspondence in the stylobate width (18.75 legacy vs. 18.746 m PG) and length (50.01 vs. 50.012 m) and the column height (5.22 vs. 5.216 m), because these measurements are of particular concern for architectural analysis and would have been taken carefully by Dörpfeld.

These are approximations of the standard error, but we can be reasonably confident that linear measurements from the PG models are unlikely to differ by much more than 20 mm from the reality. The 3-σ linear measurement error (LME) is a useful standard for architectural analysis (Luhmann 2010; Rieke-Zapp *et al.* 2009). The global LME can be estimated at 18–26 mm, whereas measurements over smaller regions — such as individual orthostate blocks that were captured within a single photograph — are more accurate, with an LME below 5 mm. Although further improvements in the PG accuracy are possible, the existing models are already well within the accuracies required for most architectural analysis (Objective #2).

Cost is perhaps the most important consideration if PG is to be widely used for the study of architecture (Objective #4). First is the hardware kit: a TS (ca. $6,000), the camera (ca. $4,000), a computer with adequate RAM (ca. $3,000), and the software (*c.* $500). The DAP will acquire a boom for raising the camera above the level of the Heraion columns (*c.* $1,500). This kit can be reused for many jobs, and both the TS and a laptop computer are commonplace

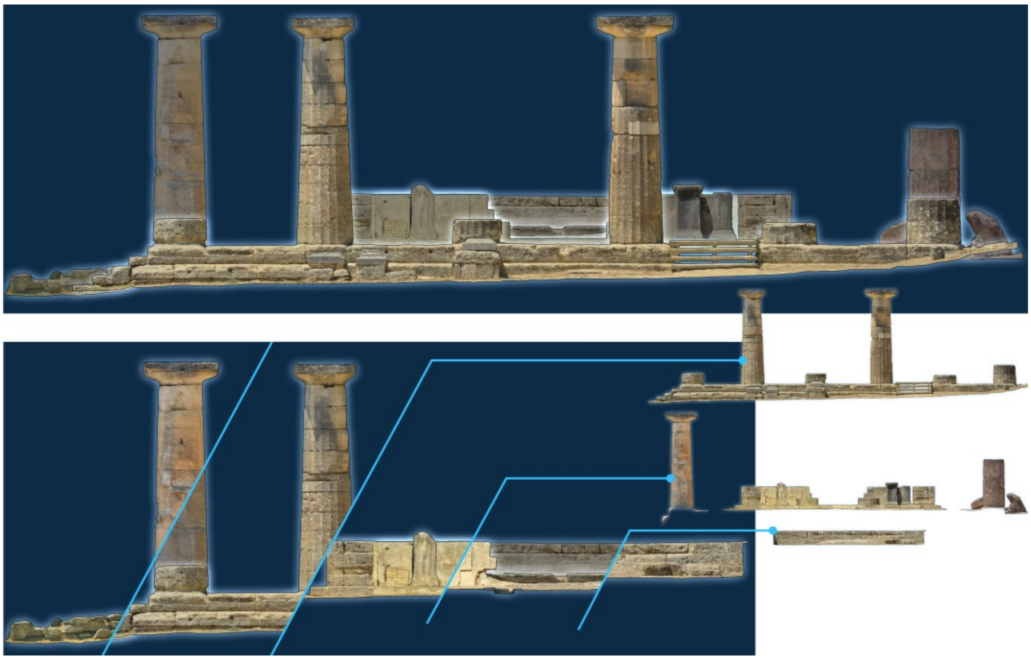

Figure 4 East elevation from the Heraion as 2.5D slices (DAP, © 2013 Sapirstein)

in fieldwork and can be borrowed or rented at minimal cost. If this hardware kit is used repeatedly, a budget of ca. $1,000 per project is conceivable.

Labor costs depend on the setting of the projet and are better reported by the hour. The TS survey lasted two days with a two-person crew (30 crew-hours). Two workers took four days to clean the site before photography (60 hours). Excluding practice sessions, photography was completed in three days (20 hours). Preparing the data in the software took 40 hours, spread out over two weeks between calculations. Cleaning, exporting, and rendering the tiles into combined 2D projections—described below—required ten days, due to some mistakes and experiments with the procedure, though could be streamlined to five days (40–80 hours). Altogether the Olympia project required about 130–170 hours for technicians and 60 hours of manual labour. The project was completed in five weeks: two on site, and three for rendering and exporting models.

Evaluation: The DAP was largely successful in meeting the five objectives laid out above. For (1) scale, the majority of the Heraion has been recorded, although the DAP is returning with a boom for aerial photographs of the taller columns. The (2) quality meets the desired resolution of 1 mm or less per texture sample. Accuracy is superior to manual illustration, although it could be refined with the addition of aerial photographs, a fixed-focal-length lens, and coded targets. The (3) practicality is well within the standards for fieldwork in Greece, with portable, commonly available equipment and inexpensive, highly automated software that can be learned within a few weeks of instruction and practice. The (4) budget is considerably less than that of 3D recording via terrestrial laser scanning, and post-processing is fast due to the clean mesh reconstruction produced by the PG software. It also is much cheaper than manual illustration, which for the Heraion would require more TS measurements and several months of drawing. I now turn to consider the final objective (5): a viable end-product.

3. Data Management and analysis

The technical limitations of current computer software and hardware have been a major obstacle to the publication of large 3D data sets (e.g. Cignoni & Scopigno 2008; Koller *et al*. 2009). The Olympia models together contain more than 200 million vertices, two gigapixels of surface textures, and 10 gigabytes of files — far too complex for simultaneous interactive display on a desktop computer, and too bulky for efficient Internet distribution. Currently the model exists as 50 separate segments. After a final season of survey and rendering, the DAP will decimate and combine the segments into a unified model for simultaneous display. However, current GPU limitations will require the elimination of about 95% of the 3D points and 80–95% of the texture detail for rapid visualization. Being no more than a small sample of the data, such a model is useful more for publicity than analysis. Even so, the file at this resolution will contain several hundred megabytes of compressed data, and an even coarser version would be needed for embedded display on a website.

The solution adopted by the DAP is to present the temple through a series of pre-rendered high-

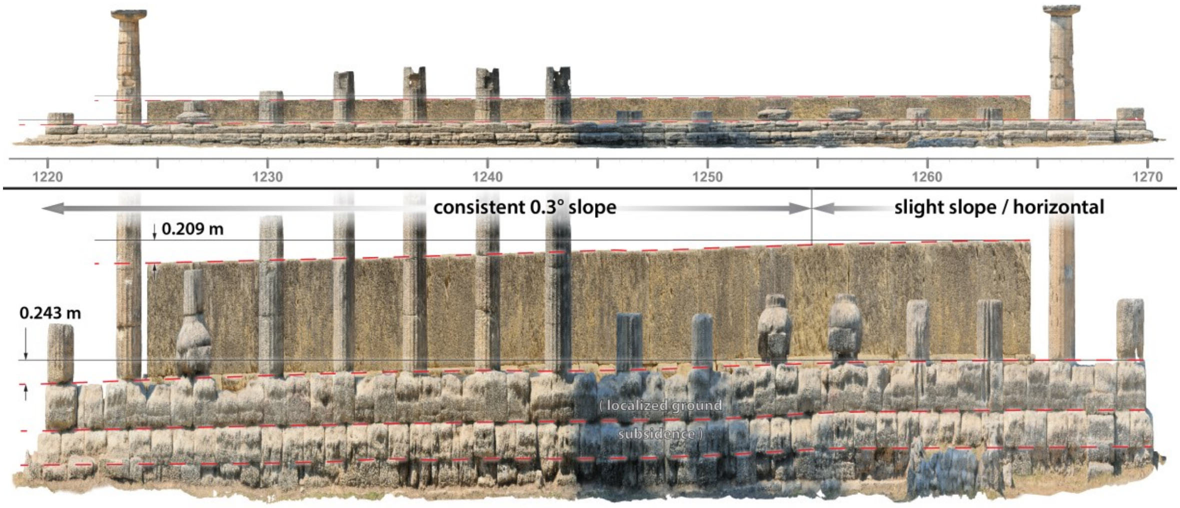

Figure 5 Horizontal inclination, viewed from the south (Below: vertical scale increased 500%; DAP, © 2013 Sapirstein)

resolution 2D views, which can be rapidly exported from the models (also see Dellepiane *et al.* 2013, De Reu *et al.* 2014). Separated into layers showing different depths of the structure, the 2D planes are orthogonal—taking advantage of the rectilinear design of the Heraion (Fig. 4). The third dimension can be retained in the flattened layers by depth-mapping, as in a DEM. This 2D/2.5D conversion has many advantages: it greatly reduces file sizes, improves interactivity, and visualizes the 3D information in a manner consistent with traditional architectural illustration, all while retaining the most critical spatial data for architectural study.

PG and architectural analysis: These 2D representations at Olympia have already led to the discovery of new features, with the potential to alter radically our understanding of the Hera temple. First, the DAP has documented clear constructional evidence to overturn the widely accepted theory that the external peristyle was initially constructed with wooden columns. Instead, these columns must have been initially executed in stone and are the same as those now *in situ*. Second, it is clear from the 3D models that the building is inclined, such that the long walls and east-west stylobates slope down substantially toward the west (Fig. 5). The consistency of these slopes throughout the building demonstrates that they were deliberately designed, although a variety of explanations can be imagined. The results will be published with my collaborator on site, David Scahill, so I will limit my discussion here to general remarks on the use of PG for analysis.

First, the PG models are as close to an objective recording as can be obtained with current methods (De Reu *et al.* 2013, 2014, Olson *et al.* 2013). Laser-scanning provides a costlier alternative to PG, and must integrate a separate camera to acquire textures at resolutions as high as those in the DAP models. This reduces the utility of laser-scans for examining the finer elements of Greek masonry such as tooling and joints. Hand-drawing is a more relevant comparison to PG, because it has been the prevailing standard for architectural recording for centuries. Drawing remains a valuable skill, but each line set to the paper reflects a choice by the illustrator. A drawing emphasizes certain elements—usually the perimeters of blocks and chiselled features—at the expense of the remainder of the building. Depending on her or his objectives and state of mind, an illustrator will often omit features during a session that may be important to another researcher. As can be seen in Figure 3 (above), the PG renderings obtained during raking light make these diagnostic features clear to an observer without eliminating other spatial and chromatic information.

The DAP recording of a subtle but consistent inclination in the Heraion platform emphasizes the importance of objectivity in recording. The slopes were briefly noted but dismissed as the result of later ground settling (Dörpfeld 1892), and all the manual renderings of the Heraion straightened out the building as if it were perfectly horizontal. Furthermore, these inclinations are difficult to record and visualize even with TS measurements due to the extensive damage of the blocks, which obscures the nature of the slope. An illustrator working on site would have difficulty understanding the nature of the slope, and like Dörpfeld would tend to turn his attention to other features of the building that are more easily intelligible to a human observer. In contrast, by collecting tens of millions of spatial measurements, the elevations from the PG model make the slopes and their consistent orientations immediately obvious. Another advantage of working with 2D imagery is that it can be compressed along one axis, like in the lower part of Figure 5, which emphasizes the slope by expanding the vertical scale by 5:1. Thus the PG analysis has revealed a critical design feature of the Heraion that has been

Figure 6 Draft design for linking remains and texts at Olympia (DAP, © 2013 Sapirstein)

overlooked for more than a century since its excavation, and is difficult to record or analyse by any other means.

Generally, the 3D data from PG allows researchers to pose questions and answer them immediately, instead of requiring a time-consuming return to the site and TS resurvey (Domingo *et al.* 2013, De Reu *et al.* 2014). One can go back repeatedly in this virtual environment to check features which were missed at first — like the sloping courses. Of course, working on the building in the field, and taking measurements by hand, still offers indispensable information. However, now that the DAP models have been created and rendered, every future visit to Olympia can be devoted to thinking through higher-level analytical problems about the temple.

4. Digital publication and the virtual museum

The 2D layers for analysis will also promote the digital publication of the Heraion. I have drafted specifications for a novel system for disseminating its models not only for publicity, but in a format amenable for detailed analysis and annotation by scholars and students alike. Currently in development, the DAP project website will allow the interactive exploration of the Heraion imagery at full resolution through the 2D layers (Fig. 6). The 3D models will be available for display at low quality embedded in the web browser, and as downloadable files for higher-quality offline display, but the core navigation will be panning and zooming through this flat, pre-rendered imagery.

The layered approach will enable the linking of the 3D models to texts and other imagery. Standard 3D data formats do not support linking with other sources of information. Methods to store annotations in 3D space are an active area of investigation, although implementations to date are experimental and have limited functionality (Aliaga *et al*. 2011, Koutsoudis *et al*. 2012, Soler *et al.* 2013, von Schwerin *et al.* 2013, Yu & Hunter 2013). There is a wide variety of information to include in a virtual museum of the Heraion in addition to its physical remains. The 3D models can be supplemented by texts, including metadata, higher-level explanatory and synthetic commentaries, and archival texts like excavation records or publications. The interface should incorporate 2D imagery, such as historical photographs or reconstruction drawings from past studies. By uniting all of the relevant knowledge about the Heraion under a single interface, the DAP website will be a 'virtual museum', replicating the types of information recorded in a print publication, even while enhancing their accessibility and clarifying their spatial relationships.

By means of web-based mapping and GIS technologies, specific coordinates or areas of the 2.5D layers from the 3D model can be linked using hypertext. This would enable a user, for example, to focus on a column setting to display further information (Fig. 6), search for all excavation notebook records referring to a particular part of the Heraion, or navigate the 3D model by clicking on features in an archival photograph. Besides providing a rich, comprehensive digital resource for the temple, this digital approach has the potential to streamline the publication process significantly. Whereas traditional architectural studies typically take a decade or more to appear in a print monograph, through this interface the DAP will be able to release high-quality imagery of the building and associated annotations as they are created. Finally, while the full 3D data set, such as the raw photographs and working models used to produce the project files, can be archived on an archaeological digital preservation service, the dissemination system described here will provide users convenient access to the polished 3D models for exploration and analysis of the Heraion.

Conclusions

In general, 3D reconstruction via PG is one of the most significant advances for the documentation and study of ancient architecture since the advent of the TS for field survey. While the TS enabled researchers to measure many 3D coordinates of points on a site, photogrammetric reconstruction offers a much greater potential. In just five weeks, the DAP successfully completed a working model of more than 95% of the Heraion, captured at 1-mm precision and rendered as a series of 3D models and layered 2D views of the building plan and elevations. Projection accuracy is good, such that linear dimensions measured from the models and images are reliable within 5 mm of reality for smaller features like individual blocks, and within 20 mm throughout the building. In addition to the high quality of the PG models, project costs and processing times are well below those of alternatives like laser-scanning or manual illustration. The data have already led to new observations about the Olympia temple and challenge the prevailing understanding of its design and phasing, which are central to hotly debated topics in architectural history such as the origins of the Doric style. The DAP plans to complete the field recording during a final season at Olympia, and then will implement the project website. This virtual museum will link the 3D models via 2D renderings to the relevant texts and images, creating a comprehensive resource for research and teaching about the Heraion.

Acknowledgments

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THE STATISTICAL IMPLICATIONS OF RECORDING CONTINUOUS VARIABLES USING ORDINAL SCALES IN BIOARCHAEOLOGICAL STUDIES

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Περίληψη/ Abstract

Το παρόν άρθρο εξετάζει την αποτελεσματικότητα των σειριακών μεταβλητών στην κωδικοποίηση υποκείμενων συνεχών μεταβλητών, γεγονός που αποτελεί συνήθη πρακτική σε βιοαρχαιολογικές μελέτες. Η ανάλυση τεχνητών δειγμάτων συνεχών, σειριακών και δυαδικών μεταβλητών έδειξε ότι η στατιστική πληροφορία που χάνεται κατά τη μετάβαση από συνεχείς σε σειριακές μεταβλητές είναι μικρή. Η χρήση τεσσάρων κλάσεων κατά τη διαμόρφωση σειριακών μεταβλητών φαίνεται να είναι επαρκής καθώς η ένταξη περισσότερων κατηγοριών δε βελτιώνει τα αποτελέσματα περαιτέρω. Αντίθετα, τα δυαδικά συστήματα καταγραφής, μια οριακή περίπτωση σειριακών μεταβλητών με δύο μόνο κατηγορίες, πρέπει να χρησιμοποιούνται μόνο σε περιπτώσεις όπου τα μεγέθη των δειγμάτων είναι μεγάλα και τα υπό εξέταση δείγματα εμφανίζουν σημαντική διαφοροποίηση μεταξύ τους ως προς τη μέση τιμή της υποκείμενης συνεχούς μεταβλητής.

The current paper examines the effectiveness of ordinal variables in coding underlying continuous variables, a common practice in bioarchaeological studies. The analysis of artificial datasets of continuous, ordinal and binary data suggests that very little statistical information is lost when ordinal variables are employed. Four-rank schemes appear to be sufficient for this purpose and the incorporation of more ranks does not improve the results further. In contrast, binary recording schemes, a marginal case of an ordinal variable with merely two ranks, should only be used when sample sizes are large and the samples under comparison exhibit substantial differentiation in the mean values of the distribution of their underlying continuous variable.

Keywords: Ordinal variables, Binary variables, Continuous variables, Statistical analysis, Bioarchaeology

Introduction

Bioarchaeological studies examine a broad range of ordinal data, such as ordinally recorded entheseal changes (Alves Cardoso & Henderson 2010, Hawkey & Merbs 1995), pathological conditions (Fairgrieve & Molto 2000, Hussien *et al.* 2009, Novak & Šlaus 2011), and nonmetric traits (Nikita *et al.* 2012). As biological phenomena, pathologies, entheseal changes and nonmetric traits exhibit a continuum in their expression. However, in order to be statistically analysed, this continuum is broken down in arbitrary ordinal or binary categories. The question that arises is how effective these constructed ordinal and binary scales are in representing the underlying continuous variables that they code. In other words, when we analyse ordinal variables, are we obtaining the same statistical results as the ones we would have obtained if we had analysed the original continuous variable?

A recent paper (Nikita 2014) approached this issue by means of artificial datasets that consisted of normally and non-normally distributed continuous variables, as well as actual data on entheseal changes from North African Late Holocene populations. The main outcome of this study was that a four-rank ordinal variable can code quite effectively an underlying continuous variable. However, in that study the continuous variables were not substantially differentiated in regards to their mean values, while the potential impact of the number of ranks used in the construction of ordinal variables was not examined. In association to the latter point, the marginal case of binary variables (ordinal variables with two ranks) was not explored. Finally, the analysis of the artificial data was based on one single dataset of a standard normally distributed continuous variable and datasets that derived from this by shifting the mean value. For the above reasons, the current paper examines this issue more systematically by employing more and diversified samples, coding the continuous variable using ordinal and binary schemes, using a broader range of ordinal ranks, performing additional statistical comparisons that involve 500 iterations, and testing the effect for different recording schemes using actual datasets of nonmetric traits from two Early Minoan (EM) assemblages.

1. Materials

Under the threshold model (Konigsberg 1990) the difference in the values of the probit function that are calculated from the percentage of cases that correspond to a certain threshold value of two samples with ordinal data is equal to the difference in the mean values of the normal distributions with unit standard deviation that are coded by the ordinal variable. Based on this observation, we may estimate the maximum difference in the mean values of the normal distributions in bioarchaeological samples. From the analysis of ordinally recorded entheseal changes (data presented in Nikita 2014) it was found that, under the threshold model, the vast majority of the differences in the probit function values among all pairs of populations is less than 1.5, whereas this difference very rarely extends beyond 2.

Making use of this result, five artificial datasets of continuous variables were initially created using the normal distribution with standard deviation equal to 1 and mean values equal to 0, 0.5, 1, 1.5 and 2, respectively. These datasets are denoted by N(0, 1), N(0.5, 1), N(1,1), N(1.5, 1), and N(2, 1). Each dataset was subsequently transformed into a binary, a four-rank and a six-rank ordinal variable. The threshold values used in these transformations were: 1 for the binary variable, the scheme (0, 1, 2) for the four-rank ordinal variable, and the scheme (0, 0.5, 1, 1.5, 2) for the six-rank ordinal variable. The initial samples N(0, 1), N(0.5, 1), N(1,1), N(1.5, 1), and N(2, 1) of the continuous variable as well as the samples arising from them with binary and ordinal data will be denoted by 1, 2, 3, 4, and 5. Finally, from samples 1, 2, 3, 4, and 5, the first 10, 20, 30, 50, and 100 cases were selected to create sub-samples.

To test the impact of different recording schemes in an actual bioarchaeological case study, the labial curvature of the upper first incisors, a dental nonmetric trait frequently employed in biodistance analysis, was recorded in two EM assemblages, namely the material from Kephala Petras rockshelter and the Livari Skiadi rockshelter. This trait was originally recorded as an ordinal variable using the Turner *et al.* (1991) scoring scheme and was subsequently transformed into binary variables using all possible thresholds for presence/absence, including the threshold proposed by Turner (1987), which is the standard for this trait in the literature. Note that in the case of the nonmetric traits, like in any bioarchaeological phenomenon, the original continuous variable is unknown, so the comparisons reported in the following section focus on the convergence between ordinal and binary variables.

2. Methods

The artificial continuous datasets N(0, 1), N(0.5, 1), N(1,1), N(1.5, 1), and N(2, 1) were formed by means of a homemade macro in Excel VBA using the Box-Muller method to generate 5×100 random numbers with a standard normal distribution (Box & Muller 1958). These datasets were further transformed into ordinal and binary variables using the threshold values given in the previous section. Subsequently, pairwise independent t-tests and Fisher's exact tests among all subsamples were run, where the independent t-tests were run for the continuous and the ordinal variables (see Nikita 2014 for the application of parametric t-tests for ordinal data), and the Fisher exact tests for the binary variable. For each statistical test, the p-value, i.e., the estimated probability of rejecting the null hypothesis when this hypothesis is true, was recorded. All statistical procedures were implemented in the same macro used to create the artificial data. Another feature of this macro was that it could create a dataset using a certain initial seed in the random-number generator or n = 500 random datasets and calculate the p-values of all pairwise comparisons for these datasets. Finally, the p-values of all pairwise statistical tests were averaged over these 500 iterations. In addition, the p-values of the 500 random datasets were used to calculate the percentage of cases where the null hypothesis of the t-test or exact test was wrongly rejected or accepted in relation to the p-value of the t-test of the original continuous variable. It is evident that this percentage gives, in fact, the probability of making a type I or II error when coding the continuous variable using a binary or an ordinal scheme. For the actual dataset of labial curvature, comparisons were performed between the two Minoan samples using independent t-tests and chi-squared tests with Monte-Carlo permutations for the ordinal variables and Fisher's exact tests for the binary data. The obtained p-values were compared.

3. Results and Discussion

Indicative results based on a single artificial dataset are presented in Figures 1 and 2. Figure 1 presents the p-values from the comparisons between samples that exhibited a difference in the mean values of the distribution of their underlying continuous variable, dm, equal to 0.5, dm = 0.5. It is seen that despite the dispersal of the data points, the p-values obtained from the ordinal data are much closer to those obtained from the original continuous variable, whereas the p-values obtained from binary data are differentiated, particularly when sample sizes are small. When the difference in the mean values of the normal distribution of the underlying continuous variable between samples increases, the difference between the p-values obtained using different coding schemes decreases as expected (Fig. 2).

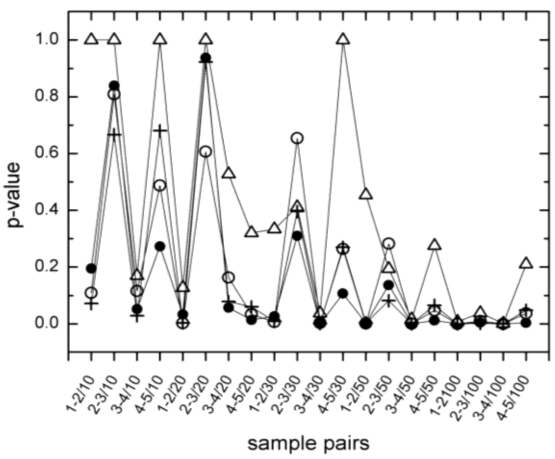

Figure 1 p-values obtained from the comparisons between samples with dm = 0.5 using independent t-tests on the continuous data (•), the four-rank ordinal data (o), the six-rank ordinal data (+) and Fisher's exact tests on the binary data (Δ).

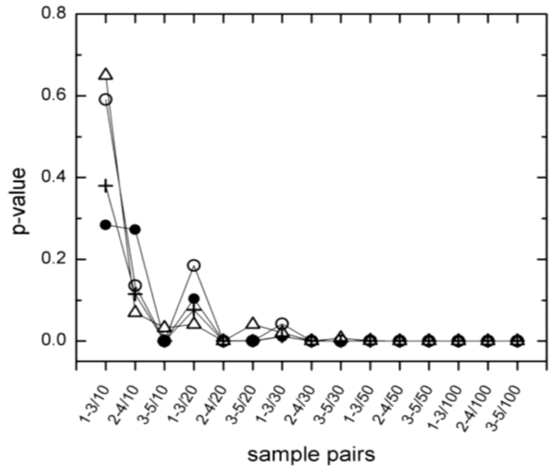

Figure 2 As in Figure 1 using samples with dm=1.

Besides, of primary importance is the probability of a type I or II error occurring when the original continuous variable is replaced by a binary or an ordinal one. In Table 1 it is shown that such errors are more frequent when a binary variable is employed in comparison to ordinal ones. Also, it appears that both ordinal schemes give largely convergent results.

Although certain patterns can be identified from the above results, the analysis of a single dataset does not allow generalizations. A better picture is obtained when the 500 artificial datasets are analysed. Figure 3 presents the mean p-values that correspond to the results given in Figures 1 and 2. We observe that both ordinal schemes again give practically identical results to those of the continuous variable. This convergence occurs irrespective of the sample sizes and dm. This suggests that ordinal variables express effectively the underlying continuous variable with minimal loss of statistical information. It is striking that an increase in the number of ranks does not improve further the performance of ordinal variables.

Sample size	Binary	Four-rank ordinal	Six-rank ordinal
10	4	1	1
20	4	0	1
30	1	0	0
50	1	0	1
100	1	0	0

Table 1 Number of cases with type I or II error.

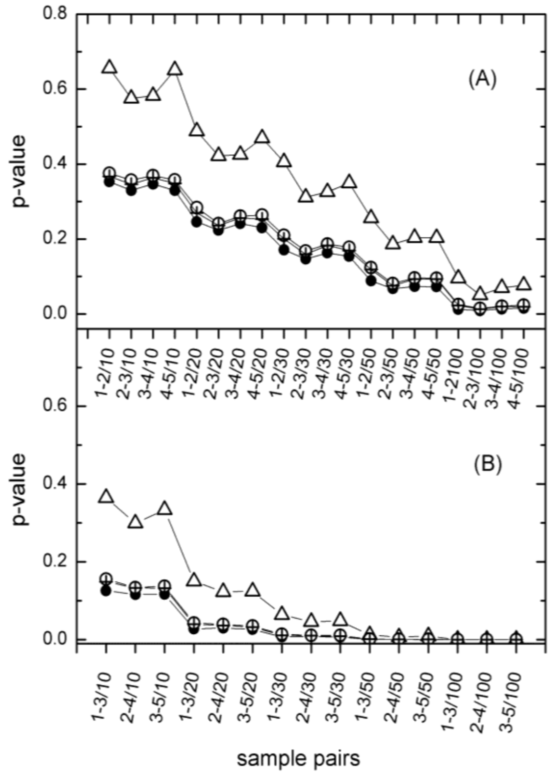

Figure 3 As in Figure 1 (A) and Figure 2 (B) for p-values averaged over 500 iterations.

In contrast, the results obtained from binary variables are largely differentiated from those of the continuous data. Figure 3 demonstrates that the replacement of a continuous variable by a binary one may be effective only for large sample sizes and for samples that exhibit great differences in the mean values of the distribution of their underlying continuous variable.

In what concerns the probability of making a type I or II error when coding the continuous variable using a binary or an ordinal scheme, the results are presented in Figure 4 and Table 2. It is seen that this probability is rather high, around 25%, for the binary variable when the sample sizes are small (10 to 20 cases) (Fig. 4), and remains high even in larger samples when dm is small (Table 2).

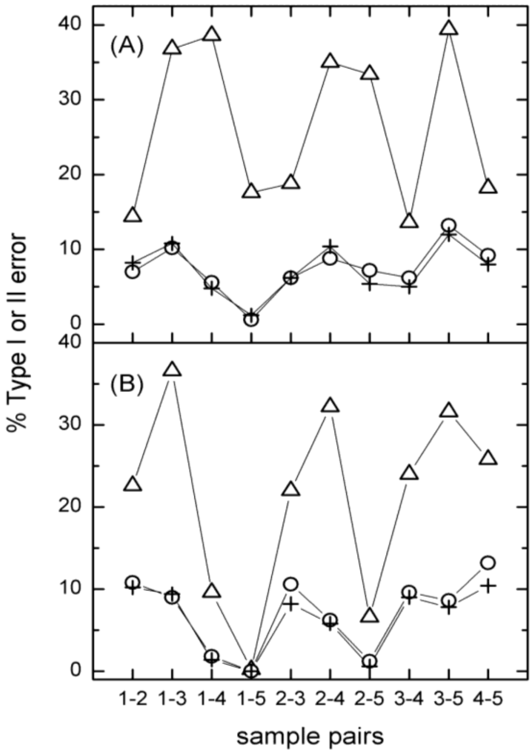

Figure 4 Percentage of type I or II error when a continuous variable is coded by a binary (Δ), a four-rank ordinal (o), and a six-rank ordinal (+) variable. Sample size =10 (A) and 20 (B).

In ordinal data, this probability is much lower. It should also be noted that even in cases where a type I or II error occurred using the ordinal data, the p-values usually did not differ significantly from the corresponding ones for continuous data. For example, the p-value obtained from continuous data may have been 0.052, whereas the corresponding ordinal p-value was 0.04.

The number of upper first incisors exhibiting different degrees of expression for labial curvature using the Turner *et al.* (1991) ordinal scheme is given in Table 3. Three different binary variables were created with the corresponding thresholds set to the degree of expression 1, 2, and 3 of the ordinal variable. Note that the threshold value equal to 2 is the standard one in the literature for this trait (Turner 1987).

The p-values obtained from the comparisons employing the ordinal variable were equal to 0.035 for the chi-squared test and 0.044 for the independent samples t-test, suggesting a statistically significant difference between the two samples in the expression of labial curvature. When the ordinal variable is transformed to a binary one, setting the threshold of presence to 1 and the comparison between populations is repeated, the obtained p-value is 0.006, which leads to the same conclusion. In contrast, when the threshold is set to 2 and 3, the p-values are 0.266 and 0.168, respectively, suggesting that the null hypothesis cannot be rejected. These results show that if the standard threshold of 2 is used, the statistical results are very different from the ones obtained from the ordinal variable. Although this dataset cannot assess the convergence between ordinal and continuous data, since the underlying continuous variable is unknown, the above results highlight the potential divergence of the results and subsequent conclusions when binary variables are constructed.

Sample pair	Binary	Four-rank ordinal	Six-rank ordinal
Size=30			
1-2	32.4	15.4	14.8
1-3	25.0	4.8	4.4
1-4	1.4	0	0
1-5	0	0	0
2-3	30.0	11.2	10.6
2-4	19.6	3.8	2.0
2-5	1.0	0	0
3-4	28.8	11.2	11.0
3-5	18.6	3.4	2.8
4-5	31.6	15.8	16.0
Size=50			
1-2	36.4	14.4	13,0
1-3	6	0.2	0.4
1-4	0	0	0
1-5	0	0	0
2-3	32,0	12.2	9.4
2-4	3.6	0.6	0.4
2-5	0.2	0	0
3-4	32.4	12.2	10.6
3-5	4.2	0.4	0.4
4-5	38.6	11.6	10.8
Size=100			
1-2	32.2	7.8	7.6
1-3	0	0	0
1-4	0	0	0
1-5	0	0	0
2-3	20.0	6.4	3.6
2-4	0	0	0
2-5	0	0	0
3-4	19.6	6.0	3.6
3-5	0	0	0
4-5	24.2	6.2	5.2

Table 2 Percentage of cases with type I or II error.

	Degree of expression	Frequency
PET	0	1
	1	25
	2	12
	3	10
	4	3
LIV	0	7
	1	15
	2	8
	3	2
	4	2

Key: PET = Kephala Petras, LIV = Livari Skiadi

Table 3 Frequency of upper first incisors exhibiting different degrees of expression for labial curvature in the two EM assemblages under study.

Conclusions

From the above results and discussion based on artificial and actual data it appears that ordinal variables can code effectively an underlying continuous one under all circumstances. The effectiveness of the ordinal variable is not practically dependent on the number of ranks employed and it appears that a four-rank scheme performs very satisfactorily. In contrast, binary dichotomies should be used with great caution. In cases of such dichotomies, the results only converge to those of the underlying continuous variable when the sample sizes are relatively large and the samples exhibit rather great differences in the mean values of their underlying continuous distribution.

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PERFORMANCE DICPLACEMENT BASED DESIGN ANALYSIS: A CONTRIBUTION TO THE DIAGNOSIS OF MONUMENTS' MECHANICAL HISTORY

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Περίληψη/ Abstract

Η παρούσα εργασία παρουσιάζει μέσα από μια σειρά μελετών περιπτώσεων μια μεθοδολογία ανάγνωσης της μηχανικής ιστορίας μνημείων, η οποία στηρίζεται στην εφαρμογή αναλύσεων με όρους επιτελεστικότητας (*performance displacement based analyses: PDBD*). Οι αναλύσεις αυτές αποτελούν σήμερα την πλέον ενδεδειγμένη φιλοσοφία προσομοίωσης της πραγματικότητας στον τομέα της ανάλυσης κτιριακών (ή και άλλων) δομών. Στον τομέα της διερεύνησης των μνημειακών δομών, η εφαρμογή τους δίνει τη δυνατότητα υπολογισμού μετακινήσεων και καταστάσεων λειτουργικότητας, αλλά και σχεδιασμού κατάλληλων μέτρων προστασίας υπό οποιοδήποτε σενάριο καταπόνησης. Η αξιοποίησή της μεθόδου ανάλυσης με κριτήρια επιτελεστικότητας σε συνδυασμό με δεδομένα από σύγχρονες μεθόδους γεωμετρικής τεκμηρίωσης (σε αλληλεπίδραση με το φυσικό περιβάλλον στο οποίο το μνημείο εντάσσεται) και με ενδελεχή διερεύνηση των ιστορικών συνθηκών που ευθύνονται για την υφιστάμενη κατάστασή της, καθιστά δυνατή την ερμηνεία της παθολογίας του μνημείου ως δομής εν συνόλω και –εφόσον τα αρχαιολογικά/ιστορικά στοιχεία το επιτρέπουν– της σύνδεσης της παθολογίας με συγκεκριμένο ιστορικό συμβάν ή συμβάντα.

This paper illustrates a methodology of understanding the mechanical history of monuments, based on the application of *performance displacement based analyses* (PDBD), through a series of case studies. These analyses are currently the most appropriate approach for the realistic simulation of building (or other) structures. As far as the monumental structures are concerned, the method gives the opportunity for calculation of permanent displacements and functional states and the design of protective measures under any loading scenario. The utilization of performance analyses based on data from contemporary methods of geometric documentation and data from a thorough investigation of the historical circumstances responsible for the monument's current state, allows the interpretation of the pathology of the monument as a whole structure, and– if the necessary archaeological/historical data exist – the relation of the pathology with particular historical event(s).

Keywords: Cultural Heritage, monuments, historic preservation, performance displacement based design analysis, non-catastrophic, interdisciplinary

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Introduction

The last fifteen years in the field of protection of cultural heritage and particularly the investigation and protection of monumental structures are characterized by a technological step which leverages the scientific "achievements" of other disciplines such as computer science, surveyor engineering, civil engineering and so on. During this period the following have been developed and disseminated:

a. very powerful computational tools at an affordable cost to be accessible by any researcher and or scholar

b. complex/complicated laboratory devices guided by computing and recording systems of high accuracy, which now allow for experiments in 'physical' scale (seismic simulators, centrifuges etc.). Moreover, dynamic phenomena in which the dependence on the time parameter is critical benefit from the capabilities of computer systems.

c. computational/software codes solving complex problems (with the development of constitutive laws describing the behaviour of materials under complex loads) with numerical methods in a user-friendly environment, which – in combination with the high computational speed – allow for high accuracy simulation of the examined cases/ problems compared with the physical reality.

These developments in interaction allow the continuous improvement of solving methods (e.g. the ‘physical’ scale experiments allow the optimal calibration of parameters used in computational codes and the improvement of constitutive laws for the mechanical behaviour of the materials) and also the deeper understanding of the observed natural phenomena. Besides, the improvement of knowledge on the behaviour of materials leads to development of laboratory techniques for a more sophisticated simulation of the reality (e.g. the recording of extra/ additional magnitudes which are important for the correct description of the test problem). At the same time, the widespread use of compatible scientific products enables interaction between all involved disciplines.

Furthermore, the utilization of methods which offer a fast recording of measuring data with high precision (e.g. topographic high precision measurements, photogrammetric surveying and/ with three-dimensional scanning, modern geophysical systems, high accuracy instrumentation for the monitoring of displacements, deformations and imposed actions (pressure, seismic accelerations, etc.) with optical fibres) can provide accurate data for the geometry of the monument and its response under characteristic actions (earthquake, precipitation and so on). Thus, in a non-destructive manner, valuable information for the material properties of the monument is gathered and local destruction with traditional sampling is avoided. In this way high accuracy simulation of the monumental structure is achieved (geometry - materials - actions) and realistic analyses to assess the current situation and stabilization measures for the monument are enabled (Egglezos 2010).

All these developments lead to a new philosophy for a realistic simulation: a transition from the force based classical approach of the ‘static’ design (forces and moments equilibrium, i.e. ‘on-off’ situations), to the analyses in terms of the structure’s performance (PDBD: performance displacement based design) that is the calculation of the structure’s response and functional states in terms of displacement (geometric state) (Priestley *et al*. 2007).

In the field of investigation and protection of monumental structures, the application of the new philosophy in structural analyses (PDBD) combined with user friendly and powerful computational tools and modern technologies allows for the easy modelling of monuments in interaction with the natural environment in which they are established. This is especially true for the monumental structures of ancient Greece, characterized by discrete structure (‘dry masonry’ structural systems) for which was not possible until recently to simulate accurately.

The analyses of monuments with discrete structure in terms of performance allows (besides the checking the static adequacy and the design of appropriate measures for their protection) the interpretation of their pathology as a whole structure and – if relevant archaeological and/or historical data exist – the correlation with the event(s) to cause the structural damages. In short, this method enables the understanding of the engineering/mechanical history of the monument (Egglezos & Moullou 2011).

1. Aims and objectives

The scope of this paper is to present a methodology which contributes to the diagnosis and the understanding of the mechanical history of standing monuments.

The objectives of the method are:

-The investigation (and evaluation) of the causes that led to the current state of the monument and the examination of relevant hypotheses.

-The interpretation of the historical events that have caused the current situation and the completion of the monument’s history.

-The non-destructive evaluation of the mechanical parameters of the materials of the monument.

-The verification of historical sources relating to events that have influenced the monumental structure.

-The design of stabilisation/protection measures based on the accurate simulation of the monument’s structure.

2. Methodology

The method in summary comprises the following steps:

-Geometric documentation of the monument’s structure in relation to the above steps combining all available data (archaeological – architectural – surveying/photogrammetric – geophysical)

-Identification of characteristic (known) historical phases (construction - loading) of the monument, for organising the corresponding computational steps (based on archaeological – historical-architectural data).

-Assignment of proper values in the mechanical parameters of the structural materials and selection of constitutive laws for the modelling of their behaviour (role of civil engineer).

-Investigation of significant loading actions that have been acted on the monument (archaeological - historical – architectural- seismological data).

-Information of the surrounding environment of the monument (geological - geotechnical, geophysical data).

-Back analyses (PBDB) in stages, based on the above information for the interpretation of the current state of the monument (or a historical phase) and calibration - evaluation of the modelling.

-Design of protection measures, based on the verified (from previous steps) proper modelling, if needed.

3. Case studies

3.a North Acropolis Circuit Wall (5th century BCE)

The case concerns the interpretation of a serious structural failure observed in an area of the Acropolis North Circuit Wall (Fig. 1, 2). The failure occurred, according to the available historical and archaeological evidence, at the end of the 18th or beginning of the 19th century and it includes a) the collapse of the upper part of the Wall in the area examined (the crown of the Wall that had been constructed of architectural members of the entablature of the Old Temple of Athena), b) significant outward lean from the vertical (7 cm) of the remaining lower part (the part beneath the crown that collapsed), c) rotation of approximately 1^{o} d) systematic cracking of the outward face of the wall (Egglezos & Moullou, 2011).

Figure 1 North Acropolis Wall. The area of interest. View from the North.

Available data/technologies used:

-Architectural-Archaeological data for the historic building phases of the North Circuit Wall (Korres 2002).

-Historical Seismicity of the Acropolis area region (Egglezos & Moullou 2011).

-Geological data of the major archaeological site (Koukis & Andronopoulos 1976).

-Photogrammetric recording (Mavromati & Moullou 2009).

-Historical testimonies from reliable gravures (Egglezos & Moullou 2011).

Figure 2 North Acropolis Wall. The area of interest. View from SE.

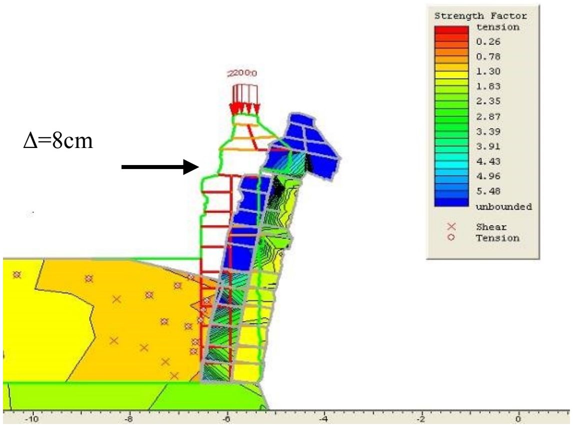

Figure 3 Interpretation of the damages

-Geotechnical data from the Acropolis area (Egglezos *et. al.* 2013).

-2-D PDBD staged analyses for the assessment of reasonable historical loading scenarios (Egglezos & Moullou 2011).

Results from the application of the method:

-Interpretation and time establishment of the overturning of embedded architectural members (cornices of the ancient Parthenon) in part of the North Wall (due to the 18th century strong earthquake from the Oropos area (Fig. 3)

3.b South Acropolis Wall (5th century BCE)

One of the severe failures of the wall concerns the permanent displacement of the crown observed in the area located in the middle of the South Circuit Wall, practically parallel to the Parthenon's south side. The reported drift is *c.* 1m in the area about the section S7 (Korres 2004) and *c.* 0.50m in the area about section S6 (Acropolis Restoration Service Internal Report).

Available data/technologies used:

-Architectural-Archaeological data for the historic building phases of the South Circuit Wall (Korres 2004).

-Historical Seismicity of the Acropolis area region (Egglezos & Moullou 2011).

-Geological data of the major archaeological site Koukis & Andronopoulos 1976.

-Photogrammetric recording (Moullou & Mavrommati 2007, Mavromati & Moullou 2009).

-Historical testimonies from characteristic historical loading and/or interventions on the Acropolis area (Egglezos *et. al.* 2013).

-Geotechnical data from the Acropolis area (Egglezos *et. al.* 2013).

-Measurements from the instrumentation systems installed in the SE area of the circuit wall (high accuracy topographic recordings, optical fibre sensors array for strain, thermal and pressure recording) (Egglezos 2010).

-2-D PDBD staged analyses for the assessment of reasonable historical loading scenarios (Egglezos 2014).

Results from the application of the method:

-Interpretation of the observed significant permanent displacement of the south wall in the area about the middle of the Parthenon, due to the combined successive action of earthquake and strong rainfall (Fig. 5) (Egglezos 2014).

-Calculation of mechanical properties of the structural geomaterials based on measurements of instrumented monitoring systems (Egglezos *et al.* 2013).

Figure 4 South Acropolis Wall. View from South

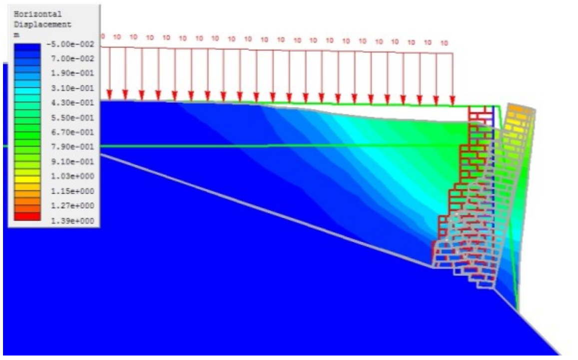

Figure 5 South Acropolis Wall section. Interpretation of the permanent displacement of the front part of the Wall (1.20m calculated Vs 1.00m measured)

3.c The ‘Great Retaining Wall’ at the Amphiareion of Oropos (late 5th century BCE / beginning of 4th century BCE)

The wall’s main structural problems comprise rotation and displacement, fractures of the stone blocks as well as loss of mass due to environmental effects. (Fig. 6). The scope of this analysis was to interpret the permanent displacements in an area about the middle of the retaining wall. In this area, according to topographic measurements the front face of the wall presents a rotation and a differential drift between the crown and the bottom equal to 20cm.

Figure 6 The “Great Retaining Wall” at the Amphiareion of Oropos.

Available data/technologies used:

-Architectural-Archaeological data for the historic building phases of the monument (Petrakos 1968, 1992).

-Historical Seismology of the Oropos region (Papazachos 2002).

-Geological data of the major archaeological site (Michopoulos 2006).

-Geotechnical data from the recent investigation (Egglezos 2012).

-Topographic recording of characteristic areas of the Great Retaining Wall (2nd Ephorate of Prehistoric and Classical Antiquities).

-2-D PDBD analyses for the assessment of reasonable historical loading scenarios (Egglezos 2012).

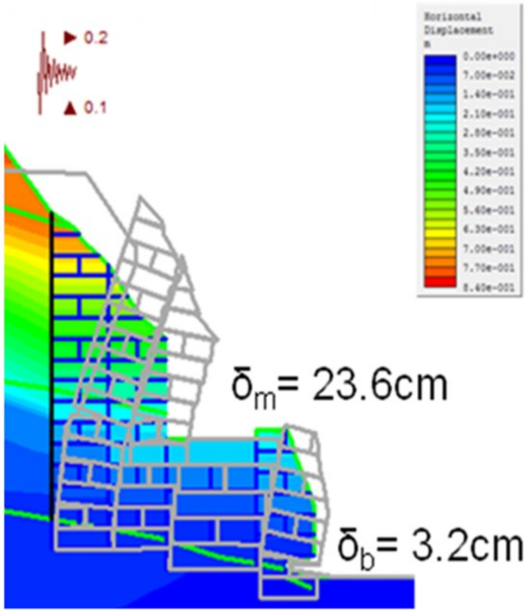

Figure 7 The “Great Retaining Wall” at the Amphiareion of Oropos section. Interpretation of the permanent displacement of the front part of the Wall (20.4cm calculated Vs 20cm measured)

Results from the application of the method:

-Determination of the causes that led to the current deformed geometry of the monument: mainly strong earthquake action (Fig.7) (Egglezos 2012).

3.d The Retaining Wall of the Treasures at the archaeological site of Olympia (4th century BCE)

The wall’s main structural problems comprise rotation and displacement, fractures of the stone blocks as well as partial collapse (of the upper part), due to soil thrust and environmental effects (Fig. 8). The scope of this analysis was to interpret the permanent displacements and rotations in an area about the middle of the retaining wall. In this area, according to topographic measurements the front face of the wall presents a rotation and a differential drift between the crown and the bottom equal to 45cm.

Available data/technologies used:

-Architectural-Archaeological data for the historical building phases of the monument (Hermann 1999).

-Historical Seismology of the Olympia region (Mariolakos 2002).

-Geological data of the major archaeological site (Mariolakos 2002).

-Geotechnical data from the recent investigation (Egglezos 2013a).

-Topographic recording of the retaining wall (7th Ephorate of Prehistoric and Classical Antiquities).

-2-D PDBD analyses for the assessment of reasonable loading scenarios (Egglezos 2013b).

Figure 8 The Retaining Wall of the Treasures at the archaeological site of Olympia.

Results from the application of the method:

-Identification of the potential causes (mainly strong rainfall action) for the deformation of the Wall (Fig. 9). This result is consistent to the observed sliding of the retained slope. The sliding is also attributed to rainfall.

-Evaluation of the ancient design and correlation to the archaeological testimonies for structural repairing interventions.

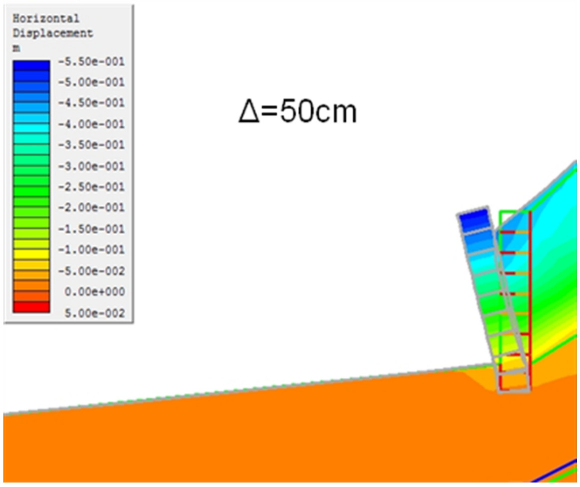

Figure 9 The Retaining Wall of the Treasures at the archaeological site of Olympia section. Interpretation of the permanent displacement of the front part of the Wall (50cm calculated Vs 45cm measured).

3.e The columns of the Opisthodomos of the Parthenon (5th century BCE)

This project concerned a) the in-situ trial load tests, which were carried out on the four, out of six, columns of the Parthenon western side, the Opisthodomos, during the recent restoration project (2001–2004) and b) the analytical assessment of their structural response (including foundation) based on the obtained experimental data (Egglezos & Toumbakari 2011).

Available data/technologies used:

-In situ test device for the application of horizontal force on the capitals of the Opisthodomos columns (Toumbakari 2007)

-Architectural drawings of the Parthenon’s Opisthodomos columns (Orlandos 1976–1978).

-Geometric data for the Parthenon’s Poros Foundation (Cavvadias & Kawerau 1907, Bundgaard 1974, 1976).

-Results of the testing project (Toumbakari 2007).

-3-D geostructural analyses on the columns with discrete and finite element modelling (Fig.10) (Egglezos & Toumbakari 2011).

Results from the application of the method: Contribution to the proper modelling of the columns of the Parthenon for the interpretation of their response under physical scale testing (application of controlled horizontal force in the capital of the columns).

Conclusion

The reliability of the method is verified, based on the results of the case studies mentioned above. It appears that the method, in principle, can be used in all monumental structures built with dry masonry in order to a) assess the existing condition b) design appropriate protection measures and c) to perform a realistic assessment of the response of the monument under any scenario stress. In particular, the described method can be a powerful tool for evaluating existing historical/archaeological data and supplementing existing information on the history of a monument, contributing to its historical and archaeological documentation.

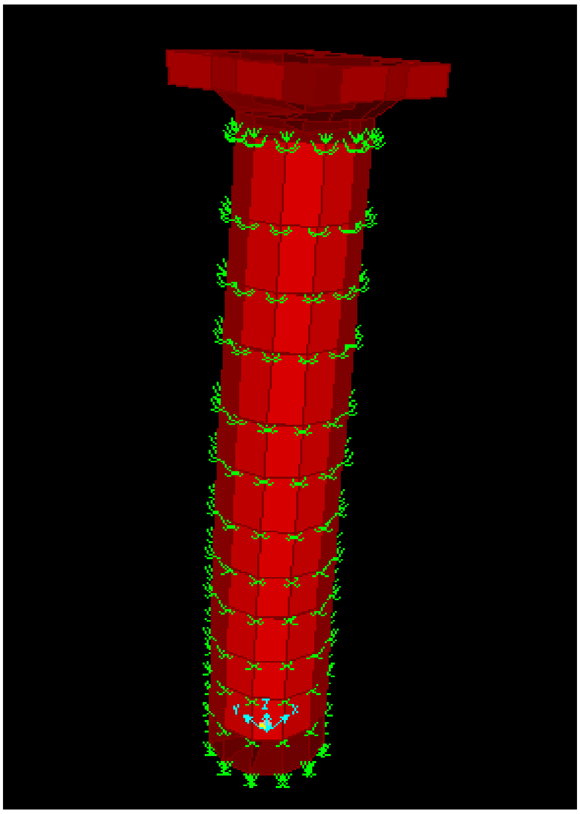

Figure 10 Accurate modelling of Opisthodomos columns for the conduction of the 3D geostructural analysis.

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METHODS AND ALGORITHMS FOR THE AUTOMATIC IDENTIFICATION OF WRITER OF ANCIENT DOCUMENTS

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Περίληψη/ Abstract

Στην παρούσα εργασία παρουσιάζονται δύο μεθοδολογίες που σκοπό έχουν την αυτόματη ταυτοποίηση χαρακτών αρχαίων επιγραφών και Βυζαντινών κωδίκων. Η ταυτοποίηση αυτή μπορεί να προσφέρει χρονολόγηση των αρχαίων εγγράφων με αδιαμφισβήτητο τρόπο. Η κυρίαρχη ιδέα αυτών των προσεγγίσεων είναι να προσδιοριστεί ένας βασικός αντιπρόσωπος από κάθε έγγραφο. Πιο συγκεκριμένα, η μία προσέγγιση κάνει εκτίμηση του προτύπου για τις επιγραφές/κώδικες, ενώ η δεύτερη μέθοδος κάνει αρχικά μια εκτίμηση της καμπυλότητας σε κάθε pixel του περιγράμματος του κάθε γράμματος. Ακολούθως, γίνονται συγκρίσεις, ανά ζεύγη, των καμπυλοτήτων που αντιστοιχούν σε δύο διαφορετικές υλοποιήσεις του ιδίου γράμματος. Στην συνέχεια εισαγάγεται μια νέα πρόταση, η οποία προσφέρει μία κλειστή λύση στο πρόβλημα του ταιριάσματος δύο ισοπληθών ψηφιακών καμπυλών κατά την έννοια των Ελαχίστων Τετραγώνων. Στο επόμενο στάδιο, εφαρμόζεται ένα κριτήριο, το οποίο ποσοτικοποιεί την ομοιότητα δύο διαφορετικών υλοποιήσεων του ιδίου συμβόλου του αλφαβήτου. Τέλος, εισαγάγεται ένας αριθμός από στατιστικά κριτήρια για την ταυτοποίηση των αρχαίων χειρογράφων.

This work presents two methodologies aiming at the automatic identification of the writer of ancient inscriptions and Byzantine codices. This identification can offer unambiguous dating of these ancient manuscripts. The basic concept of these approaches is to identify a major representative of each document. More specifically the one approach estimates a prototype for the inscription/papyrus, while the second method initially estimates the curvature at each pixel of a letter contour. Subsequently, it performs pair-wise comparisons of the curvatures sequences that correspond to two realizations of the same alphabet symbol. Then, it introduces a new Proposition that offers a closed solution to the problem of matching two equinumerous digital contours in the Least Squares sense. Next, a criterion is employed quantifying the similarity of two realizations of the same alphabet symbol. Finally, a number of statistical criteria are introduced for the automatic identification of the writer of ancient manuscripts.

Keywords: Inscriptions, Writer identification, Document classification

Introduction

The most important source for the science of History is the preserved set of written documents. Concerning Antiquity, this set mainly includes ancient stone inscriptions, and papyri. Dating the content of these documents is absolutely crucial for history and archaeology. However, writers of ancient inscriptions and papyri, as a rule, did not sign or date their documents. Thus, it is not a surprise that ancient documents dating, often causes scientific disputes and disagreements. In addition, quite frequently, the fact that important text written on inscriptions or papyri cannot be dated, generates important gaps and missing links in the knowledge and understanding of corresponding historical events. In fact, renowned historians and archaeologists, such as Prof. Christian Habich and Prof. Steven Tracy clearly state that ‘proper historical use of inscriptions can only be made if they can be dated’.

One main goal of this project is the extension and integration of an information system that will perform unambiguous dating of ancient inscriptions and papyri by automatic classification of these documents according to their writer.

1. Difficulties

Concerning ancient inscriptions writer identifications, the authors, in both approaches, had to deal with a number of serious difficulties, intrinsically associated with the nature and form of the preserved inscriptions. A list of such difficulties follows:

(a) There may frequently be essential variability of the shape of each letter in inscriptions carved by the same writer, which coexists with an underlined common trend.

(b) It is quite common, that the similarity between two specific samples of the same writer is smaller than the similarity between various samples by different writers. However, once more, one expects a statistically systematic differentiation in the realizations of an arbitrary alphabet symbol in two inscriptions, carved by different hands.

(c) Inscriptions suffer from serious wear.

(d) There may be inaccuracies and distortion in the inscriptions' images associated with intrinsic problems of the shooting process.

Two different approaches employing mathematics and computer engineering tools, have been developed, for ancient inscriptions and papyri writer identification.

2. Related work

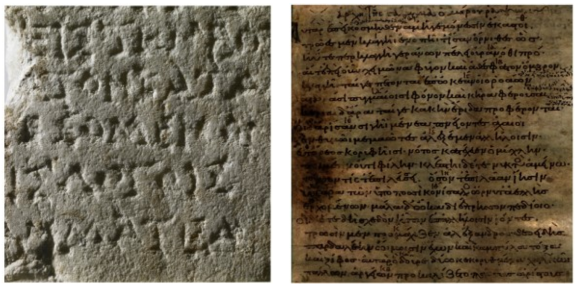
Handwritten text writer classification is a very active research topic especially concerning applications to forensics and to biometrics. In particular, Arica & Yarman (2001), present an off-line writer identification overview and Bulacu & Schomaker (2007), propose a textural methodology. Recently, on-line writer classification has attracted researcher's interest (Connell & Jain 2002) and more specifically Schlapbach *et al.* (2008), use Gaussian Mixture Models for text independent feature extraction while Cha & Srihari (2000), and Bensefia *et al.* (2005), use multiple and local features respectively.

More recently, approaches that use oriented Basic Image Feature Columns encode a writer's style as the deviation from the mean encoding for a population of writers (Newell & Griffin 2014). Jain & Doermann (2013), achieved the best overall performance at the writer identification competition (Louloudis *et al.* 2013) by using Contour Gradient Descriptors together with character segmentation to create a pseudo-alphabet for a given handwriting sample. The second best performance was achieved by Fiel & Sablatnig (2013), using a Gaussian Mixture Model and applying the Fisher kernel to create a vocabulary and then a Fisher Vector to compare documents.
A more detailed presentation of the writer identification competition results can be found in Louloudis *et al.* (2013). Gaussian Mixture Model is also used to create a supervector for writer identification and verification, offering an improvement of the accuracy of the aforementioned methods (Christlein *et al.* 2014).

Other applications of the writer identification techniques to historical documents can be found to the work of Wolf *et al.* (2011), Tracy *at al.* (2007), Panagopoulos *et al.* (2009), Schomaker *et al.* (2007), Arabadjis *et al.* (2013) and Papaodysseus *et al.* (2014).

3. Brief description

In this paper we try to combine two already proposed methodologies for the identification of the carver of ancient Greek inscriptions and papyri. Namely, we propose to use the plane curvature approach proposed in Papaodysseus *et al.* (2014) with the statistical analysis of the fitting error function proposed in Arabadjis *et al.* (2013). Examples of the documents, namely inscriptions and codices, used in this work are shown in (Fig. 1.a) and (Fig. 1.b) respectively.



(a) (b)

Figure 1 Part of an ancient Greek inscription (a) and detail from a papyrus (b).

4. Fitting letter symbols

The first approach employs the following fundamental assumption. Each writer has in his mind an ideal prototype for each alphabet symbol. From the philosophical point of view, one may consider that these ideal alphabet symbols are kinds of 'platonic' prototypes. In any case, in a strict mathematical formulation, one may consider that the ideal contour of an arbitrary alphabet symbol for a writer, is a piece-wise smooth curve. When the writer tried to carve a letter on a stone, instead of the 'platonic' prototype, he managed to carve on the stone a distorted version of the ideal smooth curve he had in his mind. Let one say that this distorted version is described by the a vector curve equation, that incorporates the noise due to hands instability, random interaction between chisel and marble, variations in the form and mood of the writer, variability of the employed instruments and in the material of the plate, etc. A first approach towards writer identification is to suppress noise from different realizations of the same letter on an inscription produced by the same writer. For example, in letter 'A' the two left most critical points define the left side of the left leg, the two rightmost ones define the right side of the right leg, etc. Thus, eventually each letter contour consists of a number of sides whose union does not necessarily cover the entire contour of the letter; however, use of these letter sides seems to offer very reliable hand identification (Panagopoulos *et al*. 2009).

The next step is to suppress noise by computing a kind of an average curve. Before evaluating this average contour, it is absolutely necessary to remove systematic discrepancies of the various realizations of an alphabet symbol on the same inscription. In order to remove randomness in orientation, each realization is rotated as a rigid body, while in order to remove variations in size it is also scaled. In other words, a realization of the alphabet symbol 'A' on the inscription is selected and each contour momentarily is considered as the reference curve. Subsequently, all other realizations of 'A' on the inscription are chosen one by one and optimally fitted each one of them to the reference curve. In order to achieve this optimal fit, the contour of the considered letter realization is parallel translated, rotated and resized and the transformed version of each contour that minimizes a properly defined error function is estimated. This error function describes the overall distance of the transformed letter contour from the reference one, in a novel manner.

After matching all realizations of the alphabet symbol 'A' on the inscription, a kind of a mean curve of the optimally fit contours bundle is estimated. It is assumed that this mean curve is a good approximation of the ideal alphabet symbol the writer had in his mind. Consequently, the term 'platonic estimation' is employed for this mean curve. In Figure 2 a cloud of matched realizations is depicted together with the corresponding mean contour (initial estimation).

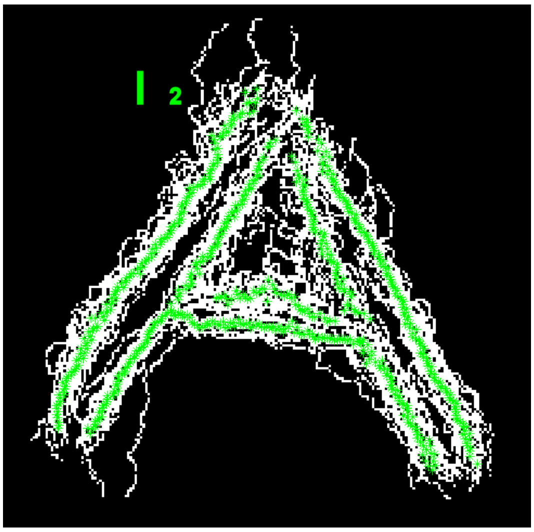


Figure 2 A first estimation of the platonic prototype of letter A.

Finally, the assumption that inscriptions written by the same hand have similar platonic estimations for most, if not all, alphabet symbols is stated and supported. An example of two optimally matched letter prototypes form two different inscriptions is shown in Figure 3, while two optimally matched letter symbols 'omega' from byzantine codices are depicted in Figure 4. Conversely, inscriptions carved by different writers give rise to platonic estimations that will be essentially different for a number of alphabet symbols of letter A. Thus, statistical criteria based on maximum likelihood estimation can be performed, which quantify these observations.

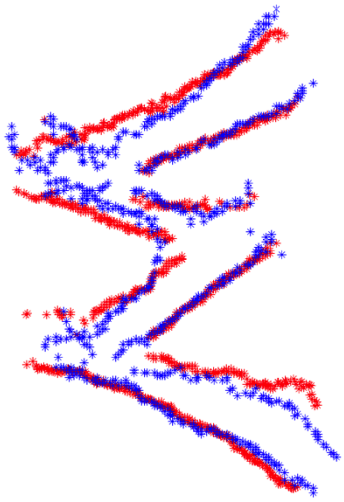


Figure 3 Matching of the ideal prototypes of two different inscriptions.

5. Curvature

The second approach takes into account the curvature of the letter contours, namely, the fitting of the letter realizations can be achieved by means of curvature since the distortion of each letter contour corresponds to tractable deformation of it.

Subsequently, the following actions have been taken:

a) Let C be the contour of an arbitrary alphabet symbol realization, appearing on a specific document. We divide C into contiguous chains of pixels, slightly overlapping. Next, we approximate each such chain of pixels with proper polynomial functions for the x and y coordinates separately, with independent variable the chain's arc-length, S. By the end of this process, each contour C of an arbitrary alphabet symbol realization is uniquely associated with a sequence of curvature values, which represent the trend of the curvature at each pixel of C, in a very satisfactory manner.

b) Suppose, now, that two contours C_1, C_2 of two different realizations of the same alphabet symbol are considered, which give rise to two distinct sequences of curvatures K_1, K_2. A mathematical approach and a corresponding algorithm are developed and applied, which achieves direct optimal matching of K_1 and K_2 via minimization of a properly chosen error function.

Subsequently, contours C_1 and C_2 are, also, optimally fitted by means of an introduced Criterion.

c) At this stage, we will use the criterion introduced in Arabadjis *et al*. (2013), which is particularly suitable for statistical considerations. This criterion forms a similarity measure between the letter contours.

d) Employing the criterion defined in the previous, we have stated and tested statistical hypotheses, which eventually indicated the number of different writers who wrote all the available documents. At the same time, a 'representative' document has been uniquely associated with each writer.

e) Each one of the remaining documents has been classified to a corresponding hand, on the basis of novel maximum likelihood estimations.

The proposed method is essentially content/text-independent. In addition, the method is applicable to contours of repeated complexes of letters or to any analogous class of similar two-dimensional curves.

Figure 4 Matching of the ideal prototypes of two different codices.

6. Application of the methods

In this section, we apply the combination of the two methods to the data set, consisting of ancient inscriptions from Agora and the Epigraphic Museum of Greece and Byzantine codices and the provided data set was the same as in Papaodysseus *et al.* (2014).

Our approach consists of applying the curvature criterion in order to fit the letter contours and the curve family satistical criterion in order to classify the documents to the corresponding writers. Optimally matched realizations of a symbol, all written by the same writer, form a bundle of distinct members of a single family of curves and a representative of each document can be formed. The similarity measures between the represenatives of two different documents can be statisticaly processed and a decision about the attribution of a document to a writer can be made.

Beginning from an arbitrary chosen inscription we make pair-wise comparisons and obtain a maximum likelihood value which offers a measure of the similarity of two inscriptions. We continue these comparisons until the likelihood is lower than a predefined threshold, namely until the two inscriptions are not similar enough and they probably belong to different hands. The method classified the 46 inscriptions into 10 different hands and this classification is shown in Table 1.

Writers	Inscriptions
Hand 1	I33, I34, I41, I19, I32
Hand 2	I9, I38, I39, I46, I6, I4
Hand 3	I17, I20, I40, I42, I43, I16, I18
Hand 4	I28, I31, I30
Hand 5	I23, I26, I27
Hand 6	I36, I35, I29, I45
Hand 7	I1, I22, I14, I25, I13, I7
Hand 8	I10, I12, I44, I15, I11
Hand 9	I2, I21, I24, I37
Hand 10	I3, I8, I5

Table 1 The classification of the inscriptions

The corresponding classification for the 23 Byzantine codices in 4 different writers is shown in Table 2. More details about the documents used in this application can be found in Colin (1909), Dow (1975), Wade – Gery (1932) and Robert (1955). Prominent experts in epigraphology, archaeology and Classical Studies fully agree with the classification offered by the system.

Writers	Codices
Hand 1	BC1, BC5, BC8, BC11, BC12, BC18
Hand 2	BC2, BC3, BC6, BC7, BC10
Hand 3	BC4, BC9, BC13, BC15, BC21, BC22, BC23
Hand 4	BC14, BC16, BC17, BC19, BC20

Table 2 The classification of the codices

The authors intend to expand the results by applying the method to an even greater number of inscriptions and Byzantine codices and by tackling further associated open subjects and disputes.

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Cultural Heritage and the Public Applications, Multimedia and the Web 2.0

ΠΕΡΙΕΧΟΜΕΝΟ ΚΑΙ ΧΡΗΣΗ ΠΟΛΥΜΕΣΙΚΩΝ ΕΦΑΡΜΟΓΩΝ ΣΤΟ «ΑΘΑΝΑΣΑΚΕΙΟ» ΑΡΧΑΙΟΛΟΓΙΚΟ ΜΟΥΣΕΙΟ ΒΟΛΟΥ

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Περίληψη/ Abstract

Μετά την ολοκλήρωση της Επανέκθεσης στην Παλαιά Πτέρυγα και της Μόνιμης Έκθεσης στη Νέα Πτέρυγα του «Αθανασάκειου» Αρχαιολογικού Μουσείου Βόλου έγινε προσπάθεια να επικαιροποιηθούν και να αναβαθμιστούν τα συστήματα πληροφόρησης των επισκεπτών, με τη χρήση νέων πολυμεσικών εφαρμογών. Στο πλαίσιο αυτό, σχεδιάστηκε και αναπτύχθηκε το Πρόγραμμα “i-Muse”, σε συνεργασία με το Κέντρο Έρευνας, Τεχνολογίας και Ανάπτυξης Θεσσαλίας (ΚΕ.ΤΕ.Α.Θ.) και το Αριστοτέλειο Πανεπιστήμιο Θεσσαλονίκης. Στην ανακοίνωση θα παρουσιαστεί ο σχεδιασμός της δομής και του περιεχομένου των πολυμεσικών αυτών εφαρμογών, καθώς και τα μέχρι τώρα αποτελέσματα από τη συστηματική τους χρήση στο Μουσείο.

After the completion of the Exhibition both in the Old and in the New Wing of Volos “Athanassakeion” Archaeological Museum, an attempt was taken to update and upgrade visitor information system, using multimedia applications. In this framework, the “iMuse” program was designed and developed in collaboration with the Center for Research and Technology of Thessaly (KE.TE.A.TH.) and the Aristotle University of Thessaloniki. This article presents the design of its structure and content as well as the results of its systematic use in the Museum so far.

Λέξεις Κλειδιά: «Αθανασάκειο» Αρχαιολογικό Μουσείο Βόλου, πολυμεσικές εφαρμογές, “i-Muse”, σύστημα ξενάγησης, εικονικές διαδρομές επίσκεψης, εκπαιδευτικά παιχνίδια.

Εισαγωγή

Οι επιστημονικοί προβληματισμοί στον τομέα των Μουσειακών Σπουδών οδήγησαν σε μεταστροφή του ενδιαφέροντος και του προσανατολισμού των σύγχρονων μουσείων από τα εκθέματα στα συμφραζόμενα τους και στον αναπαραστατικό τους ρόλο (Νάκου 2002). Παράλληλα, αναπτύχθηκε έντονος προβληματισμός αναφορικά με την εξεύρεση τρόπων ώστε να γίνουν περισσότερο προσβάσιμα αλλά και ελκυστικά για τους επισκέπτες (Sylaiou *et al.* 2009, Μπούνια 2002). Η αξιοποίηση των Νέων Τεχνολογιών είναι πια σήμερα αναπόσπαστο τμήμα της πολιτικής τους σ’ αυτόν τον τομέα, εντός και εκτός των στενών κτιριακών τους ορίων, τόσο για την εξυπηρέτηση των αναγκών επικοινωνίας με το κοινό τους όσο και για ερευνητικούς σκοπούς (Νικονάνου & Μπούνια 2012, Schweibenz 1998).

Κοινός άξονας της στοχοθεσίας αυτής είναι η ενίσχυση των μαθησιακών αποτελεσμάτων της μουσειακής επίσκεψης, με τη μάθηση να αντιμετωπίζεται ως δυναμική διαδικασία που διαμορφώνεται παράλληλα με τις προηγούμενες εμπειρίες και γνώσεις των επισκεπτών, τα προσωπικά τους ενδιαφέροντα, τις προσδοκίες και τις στρατηγικές που αναπτύσσουν, αλλά και την αλληλεπίδρασή τους με την ίδια την έκθεση ή το έμψυχο δυναμικό του μουσείου· σ’ αυτό το πλαίσιο επιστρατεύονται μέσα όπως τα εκπαιδευτικά προγράμματα αφενός κι αφετέρου το συμπληρωματικό της έκθεσης εποπτικό υλικό καθώς και ψηφιακές εφαρμογές, που καλούνται να δημιουργήσουν ή να βελτιώσουν τις «συνθήκες συνάντησης του επισκέπτη με το έκθεμα» (Νικονάνου & Μπούνια 2012, 2).

Κι ενώ παλιότερα αυτές οι εφαρμογές είχαν τη συμβατική μορφή ψηφιακών δίσκων, οι πιο πρόσφατες είναι διαδικτυακές, αναγνωρίζοντας στην πράξη την ανάγκη για ευκολότερη πρόσβαση, συχνά από απόσταση, και σε περισσότερο ρεαλιστικό επίπεδο, τόσο για λόγους προπαρασκευαστικής ενημέρωσης όσο και σαν εργαλείο ανατροφοδότησης της μουσειακής εμπειρίας, όχι απαραίτητα σε σχέση με τη φυσική της διάσταση (Νικονάνου & Μπούνια 2012, Sylaiou *et al.* 2009). Συνήθως απευθύνονται στοχευμένα στο κοινό, ομαδοποιώντας το με κριτήρια όπως η ηλικία, η ιδιότητά του ή το πλαίσιο επίσκεψης (Νικονάνου & Μπούνια 2012). Υποστηρίζονται από βάσεις δεδομένων με πολυτροπικό περιεχόμενο και ποικίλες ψηφιακές αναπαραστάσεις (Sylaiou *et al.* 2009). Προσφέρουν δυνατότητες για παρουσίαση μεγάλου αριθμού αντικειμένων χωρίς τους χωρικούς ή μουσειογραφικούς περιορισμούς που επιβάλλει ο φυσικός χώρος της ίδιας της Έκθεσης (Sylaiou *et al.* 2009, Μπούνια 2002). Στις περισσότερες περιπτώσεις δεν προϋποθέτουν ιδιαίτερες προηγούμενες γνώσεις για τα εκθέματα (Νικονάνου & Μπούνια

2012), απαιτούν, όμως, εξοικείωση με τη χρήση των πληροφοριακών συστημάτων, όπως υποδηλώνει και ο όρος «χρήστες» που αναφέρεται στο κοινό τους (Sylaiou *et al*. 2009). Σε κάθε περίπτωση, φαίνεται πάντως ότι ο διαδραστικός χαρακτήρας τους και η αλληλεπίδραση των χρηστών μαζί τους δημιουργεί νέες, διαφορετικές αναγνώσεις της μουσειακής έκθεσης, άμεσα εξαρτημένες από την ικανοποίησή τους σε επίπεδο διανοητικό αλλά και συναισθηματικό (Lee & Kim 2011).

Ειδικά σε ό,τι αφορά στις εφαρμογές που απευθύνονται σε παιδιά, η γνώση, συνήθως, διαχωρίζεται εμφανώς από το παιχνίδι, μέσω της παροχής εκτεταμένων πληροφοριακών κειμένων που θεωρούνται προϋπόθεση για την επακόλουθη παιγνιώδη δραστηριότητα (Νικονάνου & Μπούνια 2012). Στις περιπτώσεις, δε, που έχουν σχεδιαστεί με βάση παιδαγωγικά κριτήρια, έχουν κοινά στοιχεία σε κοινωνικό επίπεδο με την καθημερινότητα των παιδιών και επιτρέπουν τη συνεργασία μεταξύ τους, αποδεικνύονται ισχυροί διαμεσολαβητές της μάθησης, μέσα από ευχάριστες διαδικασίες βιωματικού χαρακτήρα (Hasier & Mackay 2001, Diamond 1986, Koran & Koran 1984, Rosenfeld 1979, 1981, Witmer *et al*. 2000), που βοηθούν τους εκπαιδευτικούς να παρακινήσουν και να προσεγγίσουν αποτελεσματικά πολλούς μαθητές ταυτόχρονα (Scarlatos 2002). Καθώς, δε, μεγάλο ποσοστό μεταξύ των επισκεπτών των μουσείων συνοδεύουν παιδιά ή νεαρά άτομα, θεωρείται χρήσιμο στις ανάλογες πολυμεσικές εφαρμογές να περιλαμβάνονται και εκπαιδευτικά παιχνίδια., ατομικά ή ομαδικά και σε διαφοροποιημένα γραφικά περιβάλλοντα, υπονοώντας ότι η δράση εκτυλίσσεται είτε σε εξωτερικό χώρο είτε στο εσωτερικό κάποιας αίθουσας μουσείου ή, ακόμη, και συνδυαστικά (Damala 2009).

1. Ο σκοπός και το πλαίσιο της έρευνας

Σκοπός της παρούσας μελέτης είναι να παρουσιαστεί ως προς τη δομή και το περιεχόμενό του το Πρόγραμμα «iMuse», που σχεδιάστηκε σαν εργαλείο εικονικής περιήγησης στο «Αθανασάκειο» Αρχαιολογικό Μουσείο Βόλου, καθώς και οι εντυπώσεις των επισκεπτών που το χρησιμοποίησαν μέχρι σήμερα.

1.α Τεχνολογίες Πληροφορίας στην υπηρεσία των επισκεπτών του «Αθανασάκειου» Αρχαιολογικού Μουσείου Βόλου.

Το 2004 ολοκληρώθηκε η Επανέκθεση των αρχαιοτήτων στην Παλαιά Πτέρυγα του Μουσείου, που περιλαμβάνει ευρήματα από τις αρχαιολογικές έρευνες στη Θεσσαλία τα τελευταία χρόνια. Τότε έγιναν και οι πρώτες προσπάθειες να αξιοποιηθεί συστηματικά η τεχνολογία για τις ανάγκες της πληροφόρησης των επισκεπτών του Μουσείου, που επιθυμούσαν να περιηγηθούν ελεύθερα σ' αυτό.

Αρχικά, εγκαταστάθηκαν, από την ΙΓ΄ Ε.Π.ΚΑ., δύο υπολογιστές με οθόνες αφής στην Αίθουσα Υποδοχής, που υποστήριζαν εφαρμογή περιήγησης στις Αίθουσες του Μουσείου, βασισμένη σε τεχνολογία Flash, και προβολή εκπαιδευτικού ντοκιμαντέρ, που χρησιμοποιούνταν περιστασιακά από τους επισκέπτες, χωρίς, ωστόσο, να αξιολογείται συστηματικά η εμπειρία από τη χρήση τους. Με την πάροδο του χρόνου, προέκυψαν τεχνικά προβλήματα, που πρακτικά δεν ήταν δυνατό να επιλυθούν, γι' αυτό και οι υπολογιστές τέθηκαν εκτός λειτουργίας.

Την ίδια περίπου περίοδο, το 2003, ο τότε Οργανισμός Προβολής Ελληνικού Πολιτισμού ανέλαβε το σχεδιασμό και την υλοποίηση του έργου, με το είδος και το εύρος των πολυμεσικών εφαρμογών που θα υλοποιούνταν να εξαρτάται από την επισκεψιμότητα των Μουσείων, ομοιόμορφα παντού. Το Αρχαιολογικό Μουσείο Βόλου ήταν ένα από τα 30 Μουσεία «μεσαίας επισκεψιμότητας», όπως χαρακτηρίστηκαν, για τα οποία οι πολυμεσικές εφαρμογές που σχεδιάστηκαν αποσκοπούσαν αφενός στην πληροφόρηση του κοινού κι αφετέρου στην υποστήριξη της εκπαιδευτικής τους λειτουργίας, με δεδομένη την έλλειψη, τότε, οργανωμένων εκπαιδευτικών δράσεων (Styliaras & Kokkinaki 2008, Styliaras 2009). Βασίζονταν σε τεχνολογία Flash και θα περιείχαν τρισδιάστατες και πανοραμικές λήψεις και αναπαραστάσεις εκθεμάτων και χώρων. Το πλαίσιο αυτό επέτρεπε την εισαγωγή πολύγλωσσου περιεχομένου για την περιγραφή των εκθεμάτων, την ιστορία του Μουσείου και τη διασύνδεσή του με επιλεγμένα αξιοθέατα στην πόλη. Απευθύνονταν σε μεμονωμένους επισκέπτες ή σε ομάδες με κοινά μεταξύ τους χαρακτηριστικά, με τις πληροφορίες να διαμορφώνονται και να κλιμακώνονται, κυρίως ως προς τη γλωσσική τους διατύπωση, ανάλογα με τα ηλικιακά χαρακτηριστικά του κοινού.

Το σύστημα θα εξυπηρετούνταν από σταθμούς εργασίας και εφαρμογές πληροφοριακού και εκπαιδευτικού χαρακτήρα σε αντίστοιχους χώρους του Μουσείου. Για τις ανάγκες των τελευταίων είχε ληφθεί ειδική μέριμνα, ώστε οι υπολογιστές που επρόκειτο να εγκατασταθούν στις Αίθουσες να στηρίζονται σε καμπτόμενο βραχίονα, για να ανταποκρίνονται στις ανάγκες μικρών παιδιών ή ατόμων με ειδικές ανάγκες. Επίσης, θα είχαν τη δυνατότητα περιστροφής της οθόνης τους, ανάλογα με το ενδιαφέρον και το πλήθος των επισκεπτών γύρω τους, γεγονός που θα επηρέαζε ταυτόχρονα και αντίστοιχα τα προβαλλόμενα σε αυτήν εκθέματα. Ειδικά ως προς τις εκπαιδευτικές εφαρμογές, αυτές θα παρείχαν βοηθητικό υλικό στους εκπαιδευτικούς για την προετοιμασία της διδασκαλίας συγκεκριμένων θεματικών μέσω της παρουσίασης και ανάλυσης των εκθεμάτων σε διαδραστικούς πίνακες και εκπαιδευτικά παιχνίδια παζλ, ψηφιακής συντήρησης, κρυπτόλεξου και video-game για τα παιδιά, διαβαθμισμένα ανάλογα με την ηλικία τους (Styliaras & Kokkinaki 2008, Styliaras 2009). Τελικά, κατά την εγκατάσταση της υλικοτεχνικής υποδομής, το 2008, παραδόθηκαν μόνο υπολογιστές με οθόνες αφής για την πληροφόρηση των επισκεπτών, ένας ανά Αίθουσα, που ήταν εγκιβωτισμένοι σε ορθογώνιο μεταλλικό πλαίσιο. Δυστυχώς, το σύστημα κατέστη πολύ γρήγορα ανεπαρκές, με το περιεχόμενο να αναφέρεται αποκλειστικά στα εκθέματα αφενός και καθόλου στο χώρο του Μουσείου, ενώ συχνά δεν ανταποκρινόταν σωστά κατά τις επιλογές των χρηστών, προβάλλοντας λάθος εκθεσιακές ενότητες και αντικείμενα. Και σ' αυτήν την περίπτωση, πάντως, οι εντυπώσεις των επισκεπτών από τη χρήση του δεν καταγράφονταν ούτε αξιολογούνταν. Γρήγορα προέκυψαν και τεχνικά προβλήματα στις ίδιες τις συσκευές, που οδήγησαν στην οριστική απενεργοποίησή τους.

Στη νέα μόνιμη Έκθεση στη Νέα Πτέρυγα του Μουσείου, που έχει ως θέμα την εξέλιξη της θεσσαλικής πόλης στο μυχό του Παγασητικού κόλπου και εγκαινιάστηκε το 2009, ο ήχος και η εικόνα αξιοποιούνται σε διάφορα σημεία για να υποστηρίξουν πολυτροπικά το αρχαιολογικό υλικό. Ακουστικοί οδηγοί επεξηγούν στους επισκέπτες τις θεματικές ενότητες της Έκθεσης, σε δύο γλώσσες, ελληνικά και αγγλικά, καθοδηγώντας τους στην περιήγησή τους (Εικ. 1).

Εικόνα 1 Ακουστικοί οδηγοί, που διευκολύνουν τους επισκέπτες της Νέας Πτέρυγας του «Αθανασάκειου» Αρχαιολογικού Μουσείου Βόλου.

1.β Το Πρόγραμμα «iMuse»

Η έλλειψη οργανωμένου συστήματος κυρίως για την πληροφόρηση των επισκεπτών του Μουσείου, οδήγησε την ΙΓ΄ Εφορεία Προϊστορικών και Κλασικών Αρχαιοτήτων να αποδεχτεί την πρόταση για την υλοποίηση του Προγράμματος «iMuse – Εικονικό Μουσείο με την υποστήριξη ιστού αισθητήρων» (iMuse 2013), με σκοπό να αποτελέσει «ένα πολυεργαλείο που βοηθά τους επισκέπτες να γνωρίσουν το Μουσείο πριν ακόμη αρχίσουν να περιηγούνται στο εσωτερικό του…» (ΚΕ.ΤΕ.Α.Θ. *et al.* 2011). Πρέπει εδώ να σημειωθεί ότι ο προσδιορισμός της εφαρμογής ως «εικονικής», παραπέμπει σε μια περισσότερο «άκαμπτη» (Sylaiou *et al*. 2009, 521) εκδοχή στην υλοποίηση του, που αναφέρεται σε μια ψηφιοποιημένη παρουσίαση του χώρου και των εκθεμάτων, μέσω εσωτερικού δικτύου (intranet) σε τρία επίπεδα, στους σταθμούς πληροφόρησης της «εικονικής πτέρυγας» (Virtual Wing), σε φορητές συσκευές περιήγησης (PDAs) αλλά και στην Αίθουσα Παρουσιάσεων (Presentation Room).

Χρηματοδοτήθηκε από το Ελληνικό Κράτος, την Ισλανδία, το Λιχτενστάιν και την Νορβηγία, μέσω του Χρηματοδοτικού Μηχανισμού του Ενιαίου Ευρωπαϊκού Χώρου (ΧΜ ΕΟΧ 2004-2009). Διήρκεσε 22 μήνες και γι' αυτό συνεργάστηκαν 3 διαφορετικές ομάδες εργασίας (iMuse 2013), του ΚΕΤΕΑΘ και του ΑΠΘ, που ανέλαβαν το σχεδιασμό, τον προγραμματισμό και τη λειτουργία της πολυμεσικής εφαρμογής, υπό την επίβλεψη της ΙΓ΄ Ε.Π.Κ.Α., ως προς το περιεχόμενο και την οργάνωση της πληροφορίας.

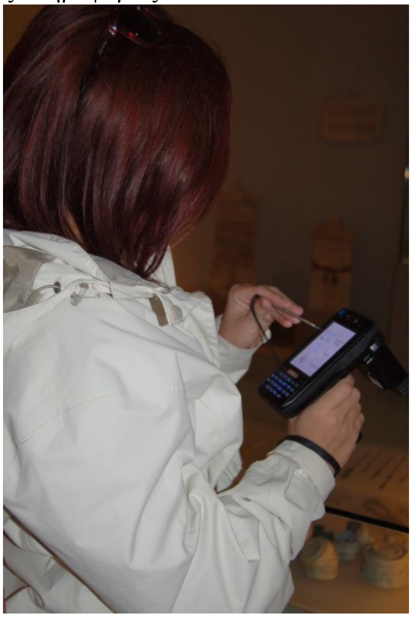
1.γ Δυνατότητες του Προγράμματος «iMuse»

Οι πολυμεσικές εφαρμογές που αναπτύχθηκαν στο πλαίσιο του Προγράμματος, χωρικά διακρίθηκαν σε τρία πεδία δυνατοτήτων εφαρμογής και χρήσης.

Η «Εικονική Πτέρυγα» εγκαταστάθηκε στην Αίθουσα Υποδοχής, για να χρησιμοποιείται από τους επισκέπτες που θα επιθυμούσαν να περιηγηθούν εικονικά στο Μουσείο, να επιλέξουν τις θεματικές της Έκθεσης ή τα εκθέματα που θα επιθυμούσαν να δουν από κοντά και άλλα συναφή, που βρίσκονται αποθηκευμένα και δεν εκτίθενται και να πληροφορηθούν περαιτέρω γι' αυτά. Οι χρήστες έχουν τη δυνατότητα να την αξιολογήσουν ψηφιακά και να καταγράψουν τις εντυπώσεις τους στο ψηφιακό βιβλίο επισκεπτών. Παράλληλα, στο σύστημα καταγράφονται στατιστικά στοιχεία για τα χαρακτηριστικά και τα ενδιαφέροντά τους, που θα μπορούσαν να αξιοποιηθούν ανατροφοδοτικά για τη βελτίωσή του (Zigkolis *et al.* forthcoming, iMuse 2013).

Η «Αίθουσα Παρουσιάσεων» δημιουργήθηκε για να καλύψει το κενό της ενημέρωσης των επισκεπτών με τη φυσική παρουσία αρχαιολόγου και να ενισχύσει τα μαθησιακά οφέλη της επίσκεψης του κοινού στο Μουσείο, μέσω του ψηφιακού περιεχομένου ενός συστήματος που υποστηρίζει τη δημιουργία και προβολή παρουσιάσεων, με αφετηρία τα εκθέματα. Οι αρχαιολόγοι του Μουσείου, οι εκπαιδευτικοί που φτάνουν σ' αυτό μαζί με τα παιδιά κατά τις σχολικές επισκέψεις ή οι ξεναγοί που συνοδεύουν τις οργανωμένες ομάδες των επισκεπτών, έχουν τη δυνατότητα, με διαφορετικό βαθμό πρόσβασης στα ψηφιακά δεδομένα ο καθένας, να δημιουργήσουν το ανάλογο εποπτικό υλικό και να το αξιοποιήσουν παιδαγωγικά (Bibi *et al*. 2010, iMuse 2013).

Οι φορητές «Συσκευές Περιήγησης» δίνουν τη δυνατότητα στους επισκέπτες να ενημερωθούν για τα εκθέματα και τους χώρους προέλευσής τους, οπτικά και ακουστικά, να ακολουθήσουν τις προτεινόμενες διαδρομές περιήγησης ή να δημιουργήσουν δυναμικά τις δικές τους είτε θεματικά είτε και με βάση το χρόνο που έχουν στη διάθεσή τους και, τέλος, να παίξουν παιχνίδια αναζήτησης επιλεγμένων εκθεμάτων του Μουσείου (Fevgas *et al.* 2010, Fevgas *et al.* 2011, iMuse 2013) (Εικ. 2). Οι φορητές συσκευές που παραδόθηκαν ήταν 5, για ισάριθμους επισκέπτες ή ομάδες επισκεπτών, που μπορούν να λαμβάνουν τις πληροφορίες που παρουσιάζονται σε smartphones, με τον περιορισμό να εντοπίζεται στο ότι οι υπόλοιποι λαμβάνουν δεδομένα μόνο για τα εκθέματα που έχει επιλέξει ο χρήστης της φορητής συσκευής, γεγονός που βιβλιογραφικά θεωρείται ότι παρεμποδίζει τη μουσειακή εμπειρία του χρήστη (Οικονόμου 2004)· έχουν, όμως, τη δυνατότητα να τροποποιούν την παρουσίαση ως προς τη γλώσσα και τα χαρακτηριστικά της ομάδας στην οποία ανήκουν. Τέλος, η εμβέλειά τους θεωρητικά φτάνει στα 2 μέτρα μακριά από τα εκθέματα, γεγονός, όμως, που σε κάποιες περιπτώσεις κατέστη δυσλειτουργικό, καθώς, λόγω της φύσης των υλικών των προθηκών του Μουσείου και της χωρικής τους εγγύτητας, σε κάποιες περιπτώσεις το σύστημα ανταποκρινόταν λανθασμένα. Για να επιλυθεί το πρόβλημα αυτό, επιλέχθηκε τεχνικά να μειωθεί η εμβέλεια του συστήματος και ως εκ τούτου ο χρήστης να πρέπει να πλησιάσει αρκετά στα εκθέματα για να λάβει τις σωστές πληροφορίες.



Εικόνα 2 Χρήση των PDAs του iMuse, κατά την περιήγηση των επισκεπτών στο Μουσείο.

1.δ Άξονες σχεδιασμού, επιλογής και οργάνωσης της πληροφορίας στο Πρόγραμμα «iMuse»

Η αρχαιολογική πληροφορία και το υποστηρικτικό της υλικό (φωτογραφίες, χάρτες, video) καταχωρήθηκαν σε βάση δεδομένων, που σχεδιάστηκε ειδικά για τους σκοπούς του Προγράμματος και επέτρεπε τη διαφορετική διαβάθμισή της ανάλογα με τις κατηγορίες των εν δυνάμει επισκεπτών του Μουσείου (παιδιά, ενήλικες, εξειδικευμένο κοινό). Τα δεδομένα αυτά αφορούν στη γενική θεματική της κάθε Αίθουσας, στις επιμέρους θεματικές των εκθετικών ενοτήτων, σε μεμονωμένα εκθέματα αλλά και σε αρχαιολογικούς χώρους.

Κατά τη φάση υλοποίησης του Προγράμματος και εξαιτίας χρονικών περιορισμών, κυρίως λόγω τεχνικών και πρακτικών ζητημάτων, δημιουργήθηκαν εξ αρχής κείμενα, παιχνίδια και προτεινόμενες διαδρομές ειδικά για μικρά παιδιά, ενώ για τους υπόλοιπους επισκέπτες του Μουσείου αξιοποιήθηκε ήδη υπάρχον ψηφιοποιημένο υλικό.

Διαπιστώσεις επισκεπτών για την ανεπάρκεια του πληροφοριακού υλικού για τους ενήλικες, οδήγησαν στην επικαιροποίησή του και στη δημιουργία κειμένων απλών και κατανοητών, για τους επισκέπτες του Μουσείου που δε διαθέτουν ιδιαίτερες αρχαιολογικές γνώσεις, αλλά και πιο λεπτομερών, για το εξειδικευμένο κοινό.

Ειδικά σε ό,τι αφορά στα εκπαιδευτικά παιχνίδια, κατά το σχεδιασμό του Προγράμματος δημιουργήθηκαν παζλ με επιλεγμένα εκθέματα του Μουσείου κι αυξανόμενο βαθμό δυσκολίας ανάλογα με την ηλικία των παιδιών, παιχνίδια μνήμης και τρισδιάστατες αναπαραστάσεις αντικειμένων, που προσφέρονταν για οπτική εξερεύνηση, τα οποία, όμως, μέχρι στιγμής δεν έχουν παραδοθεί προς χρήση. Αυτή τη στιγμή βρίσκονται σε λειτουργία στα PDAs του iMuse, παιχνίδια με τη μορφή «κυνηγιού θησαυρού» στο Μουσείο, αποτελούμενα από τέσσερις ερωτήσεις για επιλεγμένα κάθε φορά εκθέματα, θεματικά συνδυασμένα μεταξύ τους, που απαιτούν, για την επιτυχή ολοκλήρωση του παιχνιδιού, τον εντοπισμό τους στο χώρο. Τις ερωτήσεις διατυπώνει ένας αρχαίος Έλληνας, σε σχεδιαστική απόδοση, που ακουμπά σε έναν κίονα, το άνω άκρο του οποίου γίνεται πράσινο αν η απάντηση είναι σωστή και κόκκινο αν είναι λάθος. Όπως σχεδιάστηκαν τεχνικά, βέβαια, σε μεγάλο βαθμό υποστηρίζουν το δασκαλοκεντρικό, συμπεριφοριστικό μοντέλο αναζήτησης της κρυμμένης γνώσης, ως μιας και μοναδικής απάντησης σε μια ερώτηση. Αναγνωρίζοντας αυτό το χαρακτηριστικό τους, σε επίπεδο περιεχομένου καταβλήθηκε προσπάθεια ώστε η διατύπωση των ερωτήσεων να γίνει με τέτοιο τρόπο ώστε να κινητοποιεί στα παιδιά μεταγνωστικές διαδικασίες κριτικής σκέψης και παρατήρησης των αυθεντικών εκθεμάτων. Ταυτόχρονα, ζητήθηκε στην ερευνητική ομάδα να δίνεται τεχνικά η δυνατότητα για παροχή δεύτερης ευκαιρίας, σε περίπτωση λανθασμένης απάντησης, με επαναδιατύπωση του περιεχομένου της ερώτησης και επιπρόσθετες πληροφορίες, για να βοηθηθούν τα παιδιά να προσανατολιστούν καλύτερα στο χώρο καταρχήν και να αναζητήσουν τα εκθέματα έπειτα, χωρίς την άμεση τιμωρία του τερματισμού του παιχνιδιού λόγω ενός λάθους.

2. Μέθοδος

Προκειμένου να αξιολογηθεί ο βαθμός αποτελεσματικότητας των πολυμεσικών εφαρμογών του Προγράμματος, θεωρήθηκε σκόπιμο να ληφθεί υπ' όψη η γνώμη όσων τις χρησιμοποίησαν τα τρία αυτά χρόνια της λειτουργίας του. Η προσέγγιση που ακολουθήθηκε είναι ποιοτική και αναζητήθηκαν, κυρίως μέσω ανάλυσης λόγου, οι κοινές ή και διαφορετικές παράμετροι που διαμόρφωσαν αυτού του είδους την εμπειρία τους στο Μουσείο.

Έτσι, για μια προκαταρκτική αξιολόγηση των φορητών «Συσκευών Περιήγησης» σε συνδυασμό με την «Εικονική Πτέρυγα», αξιοποιήθηκαν τα σχόλια του κοινού στο Εικονικό Βιβλίο Επισκεπτών του Προγράμματος, οι γραπτές τους εντυπώσεις, κυρίως στο αντίστοιχο Βιβλίο του Μουσείου αλλά και στο ανάλογο ψηφιακό του Προγράμματος, καθώς και φωτογραφικό υλικό, που υποστηρίζει τις μη λεκτικές μορφές επικοινωνίας. Στην περίπτωση των εκπαιδευτικών παιχνιδιών, η αξιολόγησή τους από τα παιδιά πραγματοποιήθηκε στη διάρκεια ενός οργανωμένου εκπαιδευτικού προγράμματος του Μουσείου και οι απόψεις τους συγκεντρώθηκαν μέσα από παιγνιώδεις διαδικασίες.

3. Αποτελέσματα

Μια πρώτη εξέταση των δεδομένων από τους χρήστες δείχνει ότι ο αλληλεπιδραστικός του χαρακτήρας του και η πολυτροπικότητα του περιεχομένου του αντιμετωπίζονται ιδιαίτερα θετικά, ενδυναμώνοντας τις εμπειρίες από την επίσκεψη στο Μουσείο, όπως διαφαίνεται σε κάποια σχόλια τους:

«Εξαιρετικό μουσείο, με πρωτότυπο οπτικοακουστικό υλικό. Συγχαρητήρια σε όσους συνέβαλαν για τη λειτουργία του μουσείου».

Λυδία Φούρκα,
Εκπαιδευτήρια «Γέννεσις»,
Ιωάννινα 13.10.2012

ή

«Very nice museum with excellent exhibition by means of the handheld devices»

Hank & Jannette from Netherlands,
June 1, 2012

Αναγνωρίζεται η προσπάθεια να προσεγγιστούν διαφορετικές ομάδες κοινού, κυρίως με γλωσσικά κριτήρια, όπως φαίνεται στο σχόλιο που ακολουθεί

«Bravo, c'est la plus belle scénographique du musée vue depuis cinq ans en Grèce! De plus les appareils enregistrés en français (pour une fois!) sont très développées !... continuez dans cette voie… Merci!

Véronique le Bras,
«Pierre de Lune», 7.5.2013

Τίθενται, όμως, και προτάσεις για περαιτέρω εμπλουτισμό του, κυρίως σε επίπεδο περιεχομένου:

«Πρωτοποριακό το ηλεκτρονικό σύστημα ξενάγησης. Εύχομαι ότι αυτό είναι μόνο η πρώτη φάση γιατί δεν μπορώ να πιστέψω ότι θα μείνει μόνο στην απλή αντιγραφή των πινακίδων που συνοδεύουν τα εκθέματα. Περιμένω μια πιο πλήρη αναφορά. Το μουσείο είναι γενικά πρότυπο και ανταποκρίνεται πλήρως στις απαιτήσεις του σύγχρονου ανίδεου επισκέπτη…»

Αλέξανδρος Γεωργίου,
Αρχαιολόγος / Β΄ Ε.Π.Κ.Α., 21.4.2013

Πρακτικά θέματα, που αφορούν σε τεχνικά προβλήματα ή έλλειψη σωστής ενημέρωσης των επισκεπτών για το Πρόγραμμα και τη χρήση του φαίνεται να ανακόπτουν τις προθέσεις τους, δηλώνοντας χαρακτηριστικά

«Le virtuel pourrait nous guider si on pouvait le télécharger sur notre mobile. Merci, pour ce beau musée »

Didies Leon,
Paris, 4.10.2013

Ως προς την «Αίθουσα Παρουσιάσεων», προς το παρόν κανείς εκπαιδευτικός ή ξεναγός δεν έχει ασχοληθεί για να προετοιμάσει την επίσκεψη της ομάδας του. Έτσι, οι παρουσιάσεις που έχουν εισαχθεί στο σύστημα χρησιμοποιούνται συστηματικά μόνο κατά τη διάρκεια των οργανωμένων εκπαιδευτικών προγραμμάτων του Μουσείου.

Σε ό,τι αφορά στα μικρά παιδιά, οι γραπτές τους εντυπώσεις για το εκπαιδευτικό πρόγραμμα «Τα χρώματα της Ίριδας», στη διάρκεια του οποίου έγινε σκόπιμα συστηματική χρήση και αξιοποίηση των παιχνιδιών του «iMuse» παρείχαν πλούσια στοιχεία. Το παιχνίδι του κυνηγιού του «κρυμμένου θησαυρού της Ίριδας» μέσα στο Μουσείο με τη χρήση των PDAs του iMuse σχεδιάστηκε ως λειτουργικό και αναπόσπαστο κομμάτι του προγράμματος, ώστε «να συνδεθούν οι ψηφιακές με μη ψηφιακές δραστηριότητες και να εμπλουτιστεί η συνολική αισθητηριακή εμπειρία των παιδιών με τη συμμετοχή όλων των αισθήσεών τους και τη σύνδεση του ψηφιακού με τον πραγματικό κόσμο» (Νικονάνου & Μπούνια 2012, 6). Τα παιδιά χρησιμοποίησαν τις φορητές συσκευές για να ανακαλύψουν τα επιλεγμένα εκθέματα με τη συνοδεία της εμψυχώτριας (Εικ. 3), της οποίας ο ρόλος, τόσο βιβλιογραφικά (Ρούσσου 2004) όσο και στη συγκεκριμένη περίπτωση, αποδεικνύεται καθοριστικός ως καθοδηγήτριας στη δόμηση της μουσειακής εμπειρίας.

Εικόνα 3 «Κρυμμένος θησαυρός»: παιχνίδι με χρήση των PDAs του iMuse, στη διάρκεια εκπαιδευτικού προγράμματος.

Εικόνα 4 Περιδιαβαίνοντας στην «Εικονική Πτέρυγα» του Μουσείου.

«Με λένε Εύα και μου άρεσε πολύ το κυνήγι θησαυρού με το ηλεκτρονικό πιστόλη.»
Εύα, Ε΄ τάξη Δημοτικού, 15.1.2013

«Μου άρεσε ο κρυμένος θησαυρός γιατί ήταν κάτι προτότυπο που δεν παίζουμε εμείς τα παιδιά κάθε μέρα»
(ανώνυμο), Ε΄ τάξη Δημοτικού, 22.1.2013
ή

«Το πρόγραμμα στο Μουσείο μου άρεσε πολύ, ήταν ενδιαφέρον ειδικά το παιχνίδι στο τέλος παρ' ότι χάσαμε. Εύχομαι αυτό κάποτε να ξαναγίνει.».
Πάρις, Δ΄ τάξη Δημοτικού, 24.1.2013

[1] Κατά την παρουσίαση των απόψεων των παιδιών, τα κείμενά τους παρατίθενται αυτούσια, ως προς τη διατύπωση ή την ορθογραφία.

Μιλούν συγκεκριμένα για τα τεχνικά προβλήματα και τις πρακτικές δυσκολίες που αντιμετώπισαν, χωρίς, όμως, αυτές να αλλοιώνουν τις θετικές τους εμπειρίες, λέγοντας

«Αυτό που μου άρεσε είναι στο τέλος αλλά ο κύριος αυτός δέν μας άφησε να πυροβολήσουμε.»
Νικήτας, Ε΄ τάξη Δημοτικού, 17.1.2013
ή

«Στο μουσείο πέρασα υπέροχα αλλά πιο πολύ μου άρεσε αυτά που τρόγαμε με κλιστά μάτια. Αλλά το μικρό τεστάκι και το κηνίγη θησαυρού πέρασα απέσια γιατί μας μπλόκαρε το μηχάνημα αλλά πέρασα Υπέροχα. Ευχαριστούμε πολύ».
Φραντζέσκο, Ε΄ τάξη Δημοτικού, 17.1.2013

Τέλος, σε επίπεδο απλής παρατήρησης της συμπεριφοράς των επισκεπτών πρέπει να σημειωθεί ότι οι οθόνες αφής της «Εικονικής Πτέρυγας» προσελκύουν το ενδιαφέρον αμέσως κατά την άφιξή τους, ειδικά των παιδιών (εικ. 4). Συχνά, όμως, η ενασχόλησή τους με το μέσο διαρκεί λίγο και περιορίζεται απλώς στην εντατική προσπάθεια όσων περισσότερων γίνεται να «πατήσουν πολλά κουμπιά», χωρίς να αλληλεπιδρούν ουσιαστικά μ' αυτό και να το αξιοποιούν παιδαγωγικά, στοιχείο που συμπίπτει με τα σχετικά βιβλιογραφικά δεδομένα (Οικονόμου 2004, Roussou 2004).

Συζήτηση

Τα δεδομένα που συγκεντρώθηκαν δεν επιτρέπουν περαιτέρω γενικεύσεις, εξαιτίας, κυρίως, του μικρού δείγματος των συμμετεχόντων, είναι, όμως ενδεικτικά, των αντιλήψεων τους για το υπό εξέταση ζήτημα.

Σε επίπεδο προκαταρκτικών παρατηρήσεων, μπορεί προς το παρόν να λεχθεί ότι στη συγκεκριμένη περίπτωση, όπως και βιβλιογραφικά (Ρούσσου 2004), διαπιστώνεται δισταγμός από την πλευρά του φυλακτικού προσωπικού του Μουσείου, που είναι αρμόδιο για την ενημέρωση του κοινού για τις δυνατότητες και τη χρήση του συστήματος και την παροχή των συσκευών στους επισκέπτες όπως κι εκ μέρους των επισκεπτών να τις χρησιμοποιήσουν κατά την περιήγησή τους στο Μουσείο, πιθανόν λόγω μη εξοικείωσης με την τεχνολογία ή λόγω του φόβου απέναντι στο καινούριο.

Σε ό,τι αφορά στα παιδιά, παρά το περιορισμένο πλαίσιο χρήσης των πολυμεσικών εφαρμογών, φαίνεται ότι η ενσωμάτωσή τους σε οργανωμένο εκπαιδευτικό πλαίσιο έδωσε στους μικρούς χρήστες τη δυνατότητα να ανακαλύψουν από την αρχή το Μουσείο, μέσα από βιωματικές εμπειρίες που τους προσέφεραν χαρά, και μέσα από παιχνίδια που παρακίνησαν την περιέργειά τους κι έτσι, τα ενέπλεξαν με την Έκθεση, σε φυσικό, συναισθηματικό και διανοητικό επίπεδο, στοιχείο που κινείται παράλληλα με τα πορίσματα της σχετικής βιβλιογραφίας (Economou 1999, Damala 2009, Lee & Kim 2011).

Συστηματική έρευνα κοινού που βρίσκεται αυτή τη στιγμή σε εξέλιξη και θα ολοκληρωθεί ως το καλοκαίρι, αναμένεται να ανατροφοδοτήσει το Μουσείο με ενδιαφέρουσες παρατηρήσεις αναφορικά με το βαθμό αξιοποίησης και την αποτελεσματικότητα του Προγράμματος, με τα δεδομένα αυτή τη φορά να προέρχονται από τους ελεύθερους επισκέπτες, που το χρησιμοποιούν κατά βούληση.

Το σίγουρο είναι πως η εισαγωγή των νέων τεχνολογιών στα μουσεία ως δυναμικό εργαλείο στο πλαίσιο της επίσημης ή ανεπίσημης επικοινωνιακής τους πολιτικής με τους επισκέπτες είναι δεδομένη· Ζητούμενο, σήμερα πια, αποτελεί ή θα έπρεπε να αποτελεί η συστηματική διερεύνηση της αποτελεσματικότητας τους ή μη, ανάλογα με τα κριτήρια και τους στόχους του σχεδιασμού τους, αλλά και τα ιδιαίτερα ζητούμενα και τις ανάγκες των χρηστών τους.

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THE ARCHAEOLOGICAL SPACE VIA VISITOR MOVEMENT AND INTERACTION. A HYBRID COMPUTATIONAL APPROACH

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Περίληψη/ Abstract

Η έρευνα αυτή υποστηρίζει ότι η μελέτη κάποιων τάσεων που διαπιστώνονται κατά τη διαδραστική σχέση του επισκέπτη με τον αρχαιολογικό χώρο ανοίγει νέες οδούς κατανόησης τέτοιων χώρων, για τον αποτελεσματικότερο σχεδιασμό του ερμηνευτικού προγράμματος σε εννοιολογικό και πρακτικό επίπεδο. Επιπρόσθετα, η συγκεκριμένη έρευνα αντιμετωπίζει τον αρχαιολογικό χώρο ως υβριδικό και προτείνει τις ανάλογες μεθοδολογίες για την κατανόηση της προσληψιμότητάς του από τον επισκέπτη. Σε αυτό το πλαίσιο, διερευνούμε τον αρχαιολογικό χώρο εφαρμόζοντας μία νέα – μεικτής μεθοδολογίας – προσέγγιση, η οποία συνδυάζει προηγμένες εφαρμογές πληροφορικής με πιο παραδοσιακές εθνομεθοδολογικές πρακτικές, προκειμένου να αναλύσει και ερμηνεύσει ποιοτικά και ποσοτικά ένα ευρύ φάσμα επισκεπτοκεντρικών δεδομένων. Η συγκεκριμένη ανακοίνωση παραθέτει μία σύντομη περιγραφή του αντικειμένου εργασίας και της υπάρχουσας έρευνας στον τομέα της εξέτασης της κίνησης και διάδρασης του επισκέπτη, με έμφαση στους χώρους πολιτιστικής κληρονομιάς. Τέλος, παραθέτει ένα μέρος της μεθοδολογικής προσέγγισης – με έμφαση στις εφαρμογές πληροφορικής και της στατιστικής – για την ανάλυση και αξιολόγηση της κίνησης/διάδρασης των επισκεπτών, χρησιμοποιώντας ως παράδειγμα εργασίας τον αρχαιολογικό χώρο των Γουρνιών Κρήτης.

In this research paper, we argue that patterns emerging from the interaction between visitor movement and archaeological space open up new ways of understanding such spaces and thus, provide insights to inform interpretive design at a conceptual and practical level. In addition, we postulate that hybrid spaces call for the employment of hybrid methodologies if we are to gain a better understanding of how those spaces are experienced through movement. To this end and following on from previous work, this research explores the archaeological space drawing from a novel mixed-method approach, which combines computation and ethnomethodology to perform qualitative and quantitative analysis of a vast range of visitor generated data. This paper provides a brief account of previous work on movement and interaction with a particular focus on cultural heritage sites. Finally, it suggests a novel approach for assessing visitor movement – with a particular focus on computational and statistical analyses – using as a case study the archaeological site of Gournia, Crete.

Keywords: visitor movement assessment, spatiotemporal pattern recognition, GPS tracking, cultural data mining

Introduction

Archaeological sites today, constitute rather obscure spaces; architectural remains, specific interpretive programmes alongside their contemporary infrastructures (physical and digital) and the effects of time and nature influence the perception of what we would call a 'hybrid setting'. It has been noted that archaeological sites are perceived as non-places and as a consequence the visitor cannot relate them to a familiar environment (Walsh 1995, 132, Lekakis 2008). However, when it comes to spatial perception and experience, it takes someone to move within these spaces and pause at locations to contemplate and process the available information. Moving around a site, pausing and combining location-based information with information acquired before or during the visit, are processes of transforming any space into a place of meaning (Tuan 1977, 6).

The relationship of human movement with the perception of physical spaces has been identified in many disciplines as an attractive topic of theoretical and scientific endeavour. The realisation of the importance and establishment of research on the links between human movement and space, led to the acknowledgment of the benefits of studying this relationship for assessing and designing more adaptable environments to society's needs. Within the Cultural Heritage sector, museum studies have demonstrated remarkable advances in this field, and the relationship of visitor movement and interaction with space and exhibits has been heavily explored (Bitgood *et al.* 1988, Serrell 1998, Peponis *et al.* 2004, Kaynar 2005, Rohloff 2011, Yalowitz & Bronnenkant 2009). Although not numerous, there is an ever growing body of work in studying visitors' responses to cultural heritage sites in order to inform interpretation programmes. However, the 'visitor perception' approach is still left under explored in interpretive planning as it is considered to be more of a theoretical endeavour of the discipline rather than a 'factor that can be scientifically measured' and thus, put into heritage practices (Lekakis 2008).

1. Background and Aims

So far, it has been ascertained that methods such as unobtrusively observing visitor behaviour and engaging visitors in discussions can significantly inform interpretation planning or the design of digital interpretive media, as it provides insights about what visitors value the most and how they interact with and move within heritage spaces (Ciolfi & McLoughlin 2011). Descriptive analysis of visitors' movement looking at temporal and spatial patterns of their activities is usually employed as a preliminary phase to inform later development stages of more refined analysis (Fennell 1996). There is also significant work in tracking visitor movement for assessing the impact of visitor flows in heritage sites (Wallace 2013) and more rigorous methodologies developed to investigate collected time-space data (Shoval & Isaacson 2010, Russo *et al.* 2010). Much of the latter work, however, is mainly concerned with either tourist mobility research questions or with the development and refinement of methodologies for investigating pedestrian mobility. Some of these research objectives concern tourists' decision making, spatial cognition and the exploration abilities of tourists (Xia *et al.* 2008), movement patterns and flows within urban centres (McKercher & Lau 2008) and space/destination consumption. The latter category is concerned with identifying the hot spots of urban centres according to tourists' time-space behaviour.

Identifying the lack of a sound methodology in exploring the visitor/archaeological space interaction, and following on from previous work (Chrysanthi *et al.* 2012) we wished to respond to this challenge and tackle certain research questions concerning the visitor-space interaction that are pertinent to the Cultural Heritage research field.

More specifically, this research argues that the patterns emerging from the interaction between visitor movement and the archaeological space open up new ways of understanding such hybrid spaces and thus, provide insights to inform interpretive design at a conceptual and practical level. In addition, it postulates that hybrid spaces call for the employment of hybrid methodologies if we are to gain a better understanding of how those spaces are experienced. To this end and following on from previous work (Chrysanthi *et al.* 2012), we explore the archaeological space drawing from a novel mixed-method approach, which combines computation and ethnomethodology and performs qualitative and quantitative analyses of a vast range of visitor driven data. The overall number of visitors who participated in this study is 109 and in total, the dataset consists of: 60 GPS tracks, 1656 images captured by visitors, 60 filled in questionnaires and several observations (for a more detailed description on the type and methodology of data gathering see Chrysanthi *et al.* 2012).

In this paper, we mainly present the computational methodologies we developed and the statistical analyses we applied in exploring visitors' movement patterns in relation to the archaeological space and with each other as well as in assessing the interpretative infrastructure based on the questionnaires and the visitor movement data we gathered. This paper uses as a case study the archaeological site of Gournia in Crete.

2. The case study

Gournia is located on a small hill, in proximity to the sea and the Gulf of Mirabello of eastern Crete. Gournia is the most characteristic of the excavated medium-sized settlements, dated to the Late Minoan I period: 1550–1450 B.C.E In 1901–1904 Harriet Boyd Hawes excavated part of this Minoan town, revealing a system of cobbled streets, houses, drainage, a central building with court on the top of the hill which is considered by some to be a small palace, and a cemetery (Boyd Hawes *et al.* 1908, Preziosi 1983, Davaras 1989, Soles 1991).

The archaeological site today is open to the public and of all sites in the Aegean region it gives the visitor a good idea of how a Minoan town looked like. There is also an on-going excavation led by Buffalo University and conservation works mainly at the northern and central part of the site.

The reason we chose Gournia for developing and testing the visitor movement methodology is that apart from its well preserved ancient path system and structures, it presents a case with minimum interventions and a subtle interpretative infrastructure mainly limited to the few but well-designed information boards which were implemented by the local antiquities service (ΚΔ' Ephorate of Prehistoric and Classical Antiquities of Greece) in collaboration with the Institute of Aegean Prehistory Study Center for East Crete (*INSTAP*) (eight information boards exist at present). Furthermore, the lack of on-site guards in combination with low visitor numbers allows a unique experience to the visitors since they can intuitively move around and freely explore the site. According to the Hellenic Statistical Authority (EL.STAT. 2012) the annual number of visitors at Gournia in 2011 was just 10,728.

The visitor enters and exits the fenced off archaeological site from the NE, where a small ticket house is situated. Apart from the ticket house and a chemical toilet near the entrance of the archaeological site there are no other visitor facilities or designated rest points while only a few trees scattered around the site provide natural shading. It is worth noting that the visitor data were collected during a number of field sessions from 2011–2013, and that the visitors who participated in the study were not accompanied by a tour guide.

3. Time-Space Analyses

This part of the methodology mainly concerns the employment of different time-space analyses of visitors' GPS tracks in order to identify overlapping movement patterns, visitor flows and the locations where visitors suspended their movement and thus, dwelled in certain parts of the archaeological site.

3.a Line Density Analysis, Linear Directional Mean Analysis and Popular Points of Movement Suspension (PPMS)

In order to examine visitors' movement around the archaeological site we initially performed two Line Density analyses of visitors' GPS tracks in ArcGIS from the data retrieved in 2011 and 2013 respectively. This analysis enabled the visualisation of distinct visitor movement patterns and the observation of certain changes in movement behaviour due to specific on-site interventions that occurred throughout this period of time, such as new excavation areas, preliminary works of path construction for visitors with disabilities and the placement of new information panels (Fig. 1, 2). Additionally, we performed Linear Directional Mean analysis in several locations of the site in order to retrieve the visitor flow patterns (Fig. 1). Essentially, the visualisation of the above analyses enables Cultural Heritage experts to assess the on-site interventions with respect to the changes they bring onto visitors' circulation patterns; changes closely related to visitors' perception and thus, understanding of the archaeological space.

Moreover, we wished to test the hypothesis that movement suspension (visitors' stops) is not necessarily related to a *Point Of Interest* (POI) of the site, as designated by the archaeological site curators and the respective information panels. This hypothesis is based on observations conducted on-site where visitors stopped at various locations to inspect areas of recent excavations, enjoy the surrounding views, rest and take pictures with their family and friends.

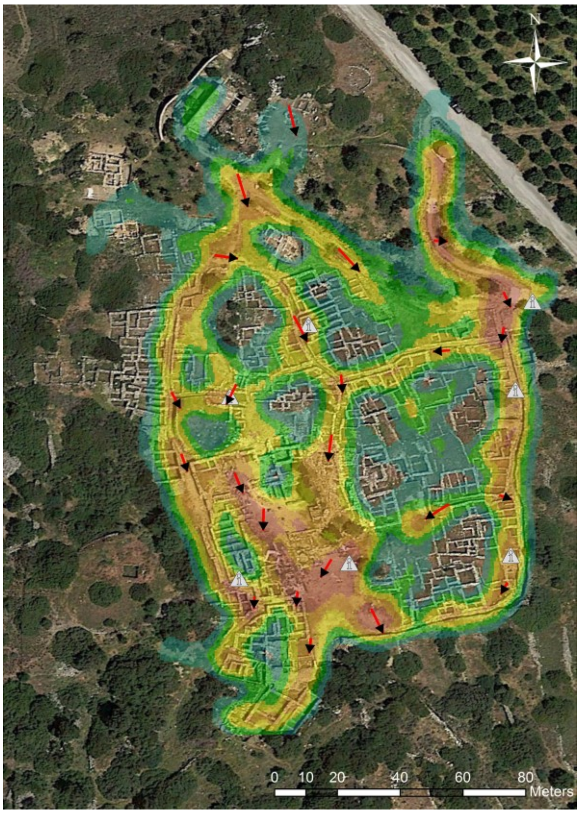

Figure 1 Satellite image of Gournia overlaid with the Line Density and the Linear Directional Mean (red arrows) analyses results of 2011 GPS data as well as the location points of information panels in 2011. Warm coloured areas indicate the density of overlapping movements. Background image (© Google Earth).

The PPMSs, depicted with blue pushpins in Figure 2, correspond to top *Best Matching Units* (BMUs) in terms of visitor passing as a result of the analysis discussed in detail in Section 3.2. While the overall modelling and analysis protocol is described in the following section, in brief, these points in space correspond to the top BMUs when the entire set of the *Self Organising Map* (SOM) nodes is ordered in terms of appearance frequency (counts) in the visitor paths. For each of the vector elements, the index corresponding to the SOM nodes (BMUs for the GPS tracks), the value is increased by a unit once a GPS track is mapped to this element. This also incorporates duration of stay since while the visitor remains in this BMU (or in a wider area that maps to this BMU) the value of the vector's element is increased repeatedly and depending on the duration of the visitor's stay in this BMU.

As it is evident from Figure 2, apart from the generated PPMSs near the POI locations there are several other locations – mainly concentrated to NW part of the site – where visitors stop. In the context of this research the authors have already conducted a HotSpot Analysis (Getis-Ord Gi*) with the geotagged images captured by visitors and a qualitative analysis of the images that form significant HotSpots (see Chrysanthi *et al.* 2012). The comparison of the results will further inform this investigation.

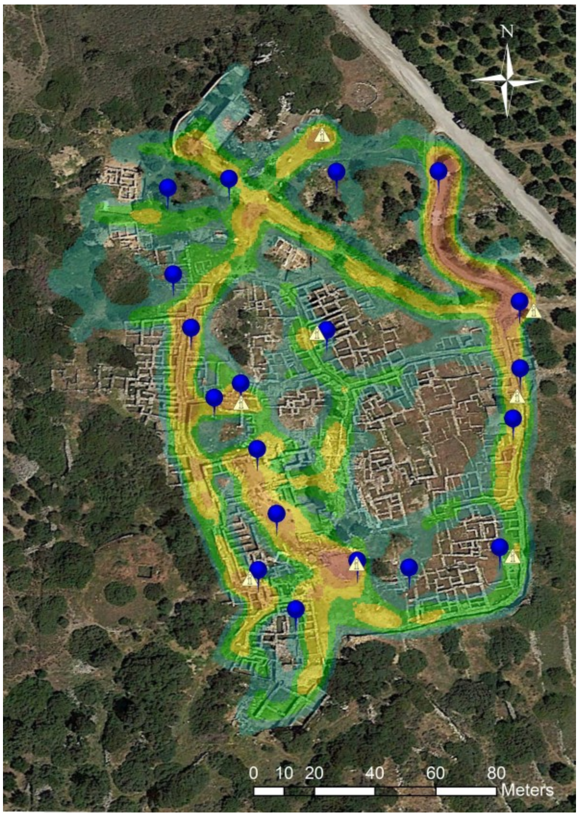

Figure 2 Satellite image of Gournia overlaid with the Line Density Analysis and the PPMS results of 2013 GPS data. Background image © Google Earth.

3.b Self-Organising Maps

Although Self Organizing Maps (SOM) are normally used as a data visualisation or dimension reduction technique (Caridakis *et al.* 2010), we choose to utilize SOM as a space modelling tool in order to derive a more abstract representation of the archaeological space and let the spatial data (GPS tracks) decide on the neighbouring relations between the map's nodes (Fig. 3, 4). The self-organising attribute of SOMs, based on node competing for representation of the samples, is a more robust and adaptable approach. Here, the weight of a SOM node is allowed to change by learning, so as to better adapt to samples in hopes of achieving the minimum distance according to some distance metric; it is this selection-and-learning process that makes the weights organise themselves into a map representing similarities. Neighbouring nodes are also affected during the learning process, thus node-neighbouring relations are learned in addition to weight learning. This is better depicted in Figure 3 illustrating the SOM's U-matrix (unified distance matrix), a representation where the Euclidean distance between the codebook vectors of neighbouring neurons is calculated and plotted.

This neighbouring characteristic is also incorporated in the overall analysis as will be discussed later and is illustrated in Figures 4 and 5. The coordinates of the GPS points from visitor paths are used to train a hexagonal, two-dimensional grid SOM with the batch mode learning procedure. The structure of the grid of the SOM units is hexagonal in order to improve quality (isotropy) of the mapping and avoid bias towards horizontal and vertical directions, while the size of the map is determined by a trial and error procedure and semi-supervised by the domain expert.

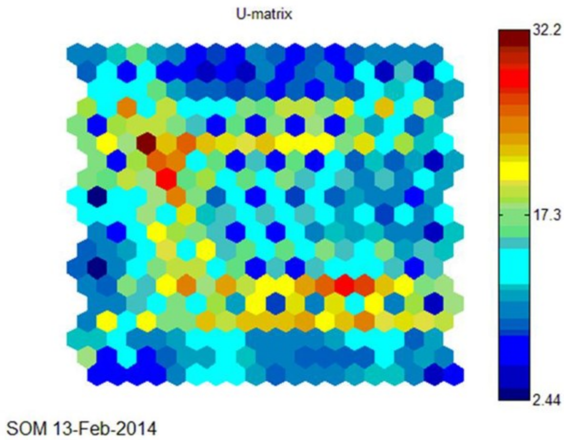

Figure 3 The U-matrix (Unified distance matrix) of the trained SOM using visitor tracks as input.

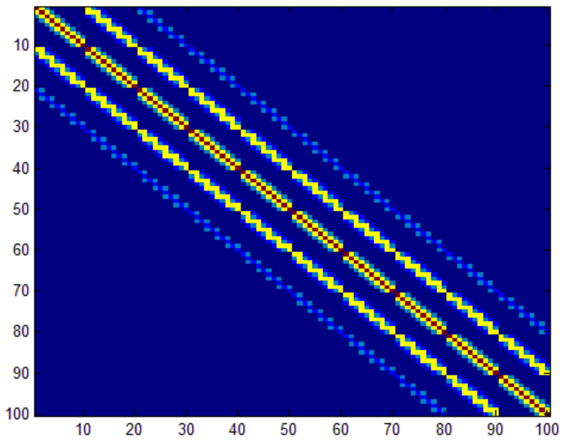

Figure 4. This figure illustrates the neighbouring relationship of the SOM nodes. Higher values (warmer colours) correspond to high correlation between the nodes whereas lower values (cooler colours) to distant neighbours. The matrix, as is the neighbouring relationship, is symmetrical and its main diagonal line equals to the unit since every node is identical to itself.

Furthermore, and given that an adequate number of visitor paths has been used to train the SOM, once a new visitor dataset is introduced to the system one can assume that no additional training is required since the space has been well modelled and represented. As a result the entire dataset of visitor paths is transformed to an ordered set of SOM nodes each corresponding to the BMU of the GPS track in the path.

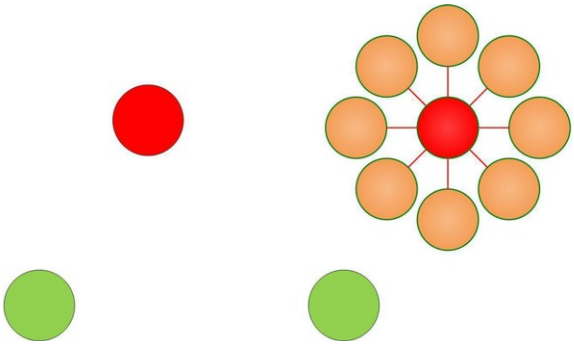

Figure 5 SOM neighboring relation illustration

4. Assessing on-site interpretative resources

In terms of assessing the on-site interpretative resources we examined the time visitors spent around the provided Information Panels (IPs). Based on the modelling approach described in Section 3.2 we mapped the IPs GPS positions to SOM nodes according to their BMU. Furthermore, we calculated the correlation of the visitor tracks to each IP. This correlation consists of both the appearance of the IP in the visitor path as well as duration and cumulative statistics as illustrated in Table 1. The analysis returned frequency data which reflect the total amount of time each visitor spent around the information panel and the respective interpreted feature of the site. We also used the results of the above analysis in combination with the questionnaire dataset in order to test a number of hypotheses. In this investigation we worked with a sample of 20 visitors who visited the site in 2013 (after the placement of the eighth information panel in the tomb area) and participated both in the GPS and Questionnaire sampling sessions. Below we present the results of two hypotheses we explored.

4.a Information panels used the most during visitors' tour

While both the Self-Organising Maps analysis and the individual examination of visitors' itineraries demonstrate clearly that visitors followed different paths during their tour around the site and accordingly visited or missed out on certain areas of the site, we wished to find out –in a robust way– 'Which of the information panels were used the most or the least by visitors during their tour?' In order to answer to this question the data were converted into two categories: 1. the first category includes cases of visitors that didn't pass by an IP and were assigned with value 0 (0=IP was not used). 2. The second category includes cases of visitors that passed/stood by an IP and were assigned with value 1 (1=IP was used).

Next, we ran a standard frequency analysis for dichotomous data in the software *Statistical Package for Social Sciences* (SPSS Statistics). The results of this analysis show that not all visitors passed by and read all the available on-site information, a fact which accords with the results of the questionnaire analysis which suggest a high demand on behalf of the visitors for more information panels (Fig. 6).

From the *Descriptive Statistics* of the frequency analysis we can also infer the minimum, the maximum and the average time spent by visitors in the designated POIs with information panels (Table 1).

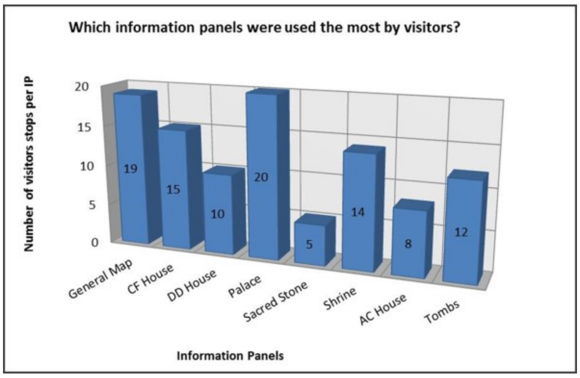

Figure 6 Graph showing the results from the statistical analysis of visitors' stops in IPs

Descriptive Statistics

Information Panels	N (visitors)	Min (sec)	Max (min)	Sum (sec)	Mean (min)
General Map	19	16	3.6	958	1.7
CF House	15	16	1.9	484	1.1
DD House	10	70	3.3	504	1.7
Palace	20	30	5.3	1049	1,7
Sacred Stone	5	2	0.6	28	0.2
Shrine	14	6	3.2	547	1.3
AC House	8	62	3.3	485	2
Tombs	12	28	3.9	573	1.6

Table 1 Table showing the Descriptive Statistics of visitors stops at each information panel.

4.b The relationship between the timeframe spent at POIs and comprehension of monuments.

At this stage of the research, we also wished to understand if there is a relationship between the time visitors spent around POIs and IPs and the level of comprehension of those POIs. Our hypothesis was that visitors who answered positively in the comprehension of POIs question (How well were you able to identify the ancient structures?) spent more time reading information from the panels or their guide books.

In order to test this hypothesis, we ran a cross-tabulation analysis in SPSS between two variables: 1.The comprehension variable which contains visitors' evaluations ranging from 'Very Well' to 'Very Bad'; and, 2. the frequency variable which contains nominal values and was formed after data were split into two timeframes: a. *Timeframe 1* (TF1) stands for the time spent at an IP location ranging from 0–15 seconds and *Timeframe 2* (TF2) stands for the time spent at an IP location for more than 15 seconds. The data were split in this way based on observations for the time required to actually read the information on the panels than just have a glance or pass by an IP. Thus, we chose to organise the data in an empirical rather than a strictly statistical manner (e.g. natural breaks, categories according to standard deviation etc.).

It is important to note that due to the limited sample of data we used here in order to demonstrate the affordances of our methodology, we cannot claim any statistical significance to the result. Nevertheless, the results of this cross-tabulation suggest that the percentage of visitors who answered the monument comprehension question positively (Very well and Fairly Well) in the TF2 group (the visitors that actually read the information panels or spent a considerable time contemplating the remains in those particular locations) is higher than the equivalent percentage in TF1 group (Fig. 7).

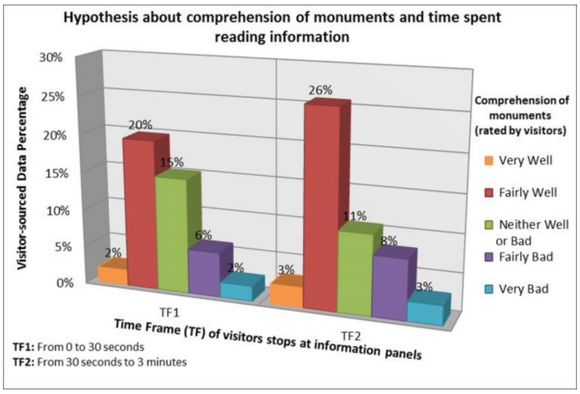

Figure 7 Graph showing the cross-tabulation analysis indicating the relationship between the timeframe spent at POIs and the comprehension of cultural information.

Discussion and Future Work

In this paper, we present part of an on-going hybrid methodology, which utilises both advanced computational analyses on visitor movement and more traditional ethnographic approaches on the visitor experience in order to explore the visitor-space interaction. This interaction is in essence the lively expression of how an archaeological site is perceived by visitors; and while, the latter is an inherently problematic notion and an active field of theoretical and scientific debate, we chose to explore the tangible results of this perception; visitors intuitive movements, dwells, interests and opinions as they are recorded by GPS devices, cameras, questionnaires and interviews respectively. This approach provides valuable insights and an effective assessment on how visitors respond to such spaces and their interpretative programmes.

In this paper we delineated aspects of our computational and statistical methodology in order to highlight some of the practical implications of exploring 'the visitor perception'. The first part of the methodology (section 3) provides valuable insights on visitor movement patterns as it enables the identification of paths or areas of the site that are used the most ('the beaten tracks' of the site) and indicates the main directions of the visitor flow as well as the locations where visitors suspended their movement (dwelled) the most. In the second part of this methodology (section 4) we wished to demonstrate that our approach can investigate more specific research questions related to the accessibility and way finding of on-site information as well as the cultural learning process.

Although, the main focus here was to present the development of our computational approaches, in the following publications we intend to evolve this work. By integrating the qualitative and quantitative analyses of this study and disseminating our results we hope that our approach provides a valuable tool set in assessing, planning and reassessing interpretative programmes and infrastructures at open-air cultural heritage sites.

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ΑΞΙΟΠΟΙΩΝΤΑΣ ΤΗΝ ΕΥΦΥΙΑ ΤΟΥ ΠΛΗΘΟΥΣ: CROWDSOURCING ΕΦΑΡΜΟΓΕΣ ΣΤΗΝ ΠΟΛΙΤΙΣΤΙΚΗ ΚΛΗΡΟΝΟΜΙΑ

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Περίληψη/ Abstract

Η παρούσα εργασία πραγματεύεται το φαινόμενο του *crowdsourcing* στην ψηφιακή Πολιτιστική Κληρονομιά και παρουσιάζει μέρος των αποτελεσμάτων μιας εκτεταμένης έρευνας σε crowdsourcing εφαρμογές πολιτιστικών οργανισμών. Εξετάζει τις διαφορετικές κατηγορίες crowdsourcing δραστηριοτήτων και προγραμμάτων που είτε έχουν υλοποιηθεί, είτε είναι σε εξέλιξη. Ακόμη, ερευνά τους παράγοντες που παρακινούν τους διαδικτυακούς επισκέπτες να συμμετέχουν ενεργά στις προσκλήσεις για αυτές τις εφαρμογές, όπως για παράδειγμα η συμμετοχή τους στην αξιόλογη προσπάθεια ενός πολιτιστικού οργανισμού, η εμπιστοσύνη και η εκτίμηση στο συγκεκριμένο πολιτιστικό φορέα, η δημιουργική διέξοδος για τον ελεύθερό τους χρόνο και η μάθηση, η ευχαρίστηση που αισθάνεται ο χρήστης από τη συμμετοχή του, η καλλιέργεια των προσωπικών του ενδιαφερόντων. Τέλος, γίνεται αναφορά στις ευκαιρίες που παρουσιάζονται με την ανάπτυξη νέων εργαλείων για τεχνολογίες *semantics*, σε ζητήματα στρατηγικής και σχεδιασμού με τη βοήθεια των crowdsourcing προγραμμάτων και αναλύονται οι περιορισμοί και η διαχείριση των δεδομένων που μπορεί να προκύψουν.

This paper discusses the crowdsourcing trend/phenomenon in digital cultural heritage and shares part of the results of an extensive survey on crowdsourcing projects/applications by Cultural Heritage organizations. The paper examines the various categories of crowdsourcing activities and showcases past and ongoing projects. Furthermore, it surveys the factors that motivate web visitors to participate actively in these calls, such as participating in a collective effort and a trustworthy project of a cultural organization, acting on trust and respect of the specific cultural institution, spending leisure time creatively and learning something, feeling contentment and pleasure when taking part in a crowdsourcing task, cultivating the user's personal interests, etc. Finally, the paper discusses the opportunities presented with the development of new tools for semantic technologies, looks at strategic and planning issues with crowdsourcing projects and considers the limitations and the management of data produced through crowdsourcing projects.

Λέξεις-κλειδιά: Crowdsourcing (Πληθοπορισμός), Πολιτιστική Κληρονομιά

Εισαγωγή

Οι ευρωπαϊκές χώρες εξακολουθούν να υφίστανται τις επιπτώσεις της παγκόσμιας οικονομικής ύφεσης, που ξεκίνησε από την κρίση που ξέσπασε το 2008, και επέδρασε αρνητικά σε κάθε είδος οικονομικής δραστηριότητας. Ένας από τους πρώτους τομείς που επηρεάστηκαν ήταν ο πολιτισμός επιδεινώνοντας και παρατείνοντας υφιστάμενα προβλήματα διοικητικής, διαχειριστικής και οικονομικής φύσεως. Ακόμη και σε χώρες όπως το Ηνωμένο Βασίλειο, υπολογίζεται ότι η τοπική χρηματοδότηση για τις τέχνες και τον πολιτισμό στην Αγγλία και την Ουαλία πρόκειται να μειωθεί μέχρι και κατά 90% μέχρι το 2020 (Gillet 2013). Η Ελλάδα, η Ιρλανδία, μαζί με την Ιταλία, την Ισπανία και την Πορτογαλία, πιο ευάλωτες από τις υπόλοιπες ευρωπαϊκές χώρες, φάνηκε ότι βιώνουν βαθύτερα τις αρνητικές επιπτώσεις της κρίσης και η ικανότητα των κυβερνήσεών τους να αντιμετωπίσουν τα προβλήματα είναι περιορισμένη.

Η κρίση επηρεάζει βαθιά όλο το φάσμα και τις λειτουργίες του πολιτιστικού τομέα, από τις υποδομές, έως την χρηματοδότηση της πολιτιστικής δραστηριότητας, από την πολιτιστική παραγωγή, έως και την κατανάλωση των πολιτιστικών αγαθών. Ωστόσο, η σημαντικότερη επίπτωση στον πολιτισμό αφορά την ελλιπή χρηματοδότηση για την παραγωγή, τη δημιουργία, τη διανομή και την προβολή των πολιτιστικών αγαθών.

Σημαντικό ρόλο στην επίλυση των παραπάνω προβλημάτων φαίνεται να παίζουν οι τεχνολογίες της *Πληροφορίας και της Επικοινωνίας* (ΤΠΕ). Στη σύγχρονη κοινωνία, που χαρακτηρίζεται και από τις ραγδαίες εξελίξεις των ΤΠΕ, υπάρχει μια στροφή προς μια κουλτούρα ενεργούς συμμετοχής και συμβολής των πολιτών σε κοινωφελείς δράσεις. Με τη βοήθεια του συμμετοχικού Διαδικτύου δίνονται ευκαιρίες στους χρήστες του να αλληλεπιδρούν με τους πολιτιστικούς οργανισμούς και από πρώην παθητικοί παραλήπτες-καταναλωτές των πολιτιστικών πληροφοριών, να μετατρέπονται σε ενεργούς πολίτες και συμμέτοχους στην προσπάθεια των μη κερδοσκοπικών πολιτιστικών οργανισμών.

1. Ορισμοί του *crowdsourcing*

Ο όρος crowdsourcing χρησιμοποιήθηκε για πρώτη φορά τον Ιούνιο του 2006 από τον Jeff Howe (2006) στο άρθρο "The rise of crowdsourcing" του Wired magazine. Η λέξη crowdsourcing, η οποία προέρχεται από το συνδυασμό των λέξεων crowd, που σημαίνει πλήθος, και outsourcing, που είναι η εξωτερική ανάθεση εργασιών, μεταφράζεται στην ελληνική γλώσσα ως *πληθοπορισμός*. Το φαινόμενο του crowdsourcing ορίζεται ως η πράξη εξωτερικής ανάθεσης καθηκόντων, που πριν εκτελούνταν από κάποιο υπάλληλο ή εταιρεία, σε άγνωστο πλήθος (crowd), ομάδα ή κοινότητα εθελοντών με ανοικτή πρόσκληση (Holley 2009). Πρόκειται για ένα μοντέλο κατανεμημένης επίλυσης προβλημάτων και λειτουργίας με τεχνολογίες Web 2.0, μέσω της οποίας μια συγκεκριμένη εργασία κοινοποιείται σε ένα ετερογενές πλήθος χρηστών με ποικίλες γνώσεις ζητώντας τους βοήθεια και λύσεις μέσω Διαδικτύου και καταργώντας τα χωροχρονικά εμπόδια. Ένας πιο αναλυτικός ορισμός (Estelles-Arollas & González-Ladrón-De-Guevara 2013) υποστηρίζει ότι το crowdsourcing αποτελεί έναν τύπο συμμετοχικής διαδικτυακής δραστηριότητας, την οποία ένα άτομο, ή ένας οργανισμός, ή μια ΜΚΟ, ή μια εταιρεία προτείνει σε ομάδα ατόμων με διαφορετικό γνωσιακό επίπεδο μέσω μιας ευέλικτης ανοικτής πρόσκλησης.

Τα τελευταία χρόνια υπήρξε μια κατακόρυφη αύξηση του περιεχομένου που δημιουργείται από χρήστες (user-generated content), τόσο με τη χρήση διαδραστικών εφαρμογών του Web 2.0, όσο και με την με πληθώρα εύχρηστων και χρηστο-κεντρικών (user-centered) χαρακτηριστικών των crowdsourcing εφαρμογών (O'Reilly 2007). Κάτι τέτοιο επέτρεψε την επικοινωνία, αλλά και τη συνεργασία μεταξύ των πολιτιστικών οργανισμών και των εθελοντών, καθώς και την προώθηση της καινοτομίας σε μεγάλη κλίμακα. Ενδεικτικό της απήχησης του crowdsourcing είναι ότι μια αναζήτηση της λέξης crowdsourcing μέσω του Google τον Ιούνιο του 2007 έδινε 44.600 αποτελέσματα, ενώ το Μάιο του 2014, 2.540.000 αποτελέσματα.

2. Επισκόπηση κατηγοριών

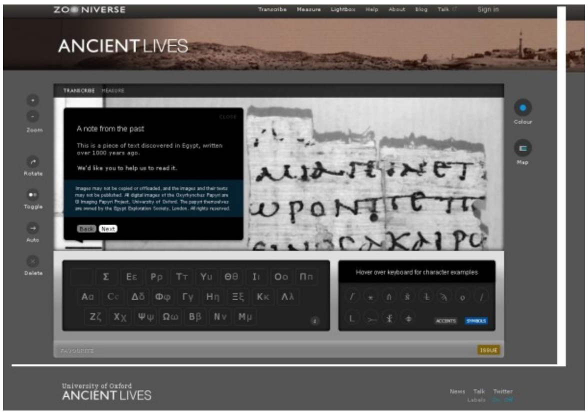
Οι Oomen & Arroyo (2011) θεωρούν ότι το crowdsourcing στους οργανισμούς πολιτιστικής κληρονομιάς και οι δραστηριότητές τους προϋπήρχαν του Παγκόσμιου Ιστού και είχαν τη μορφή της προσφοράς εθελοντικής εργασίας. Συνεπώς, το crowdsourcing μπορεί να είναι μια αποκατάσταση και ανανέωση της επίδρασης των νέων μέσων μαζικής επικοινωνίας πάνω στα παλιά με τη χρήση και δυναμική των ΤΠΕ.

Υπάρχει μια σειρά από κατηγοριοποιήσεις crowdsourcing εφαρμογών (Sylaiou *et al.* 2013). Οι τύποι crowdsourcing που χρησιμοποιούνται στον τομέα της πολιτιστικής κληρονομιάς ανήκουν σε έξι κατηγορίες:

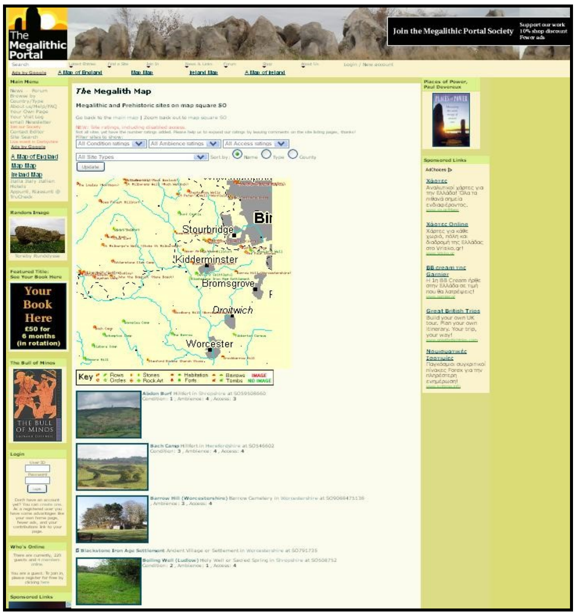
-της *διόρθωσης και μεταγραφής*, όπως π.χ. το πρόγραμμα Ancient Lives, που ζητάει από τους χρήστες τη μεταγραφή ελληνικών παπύρων (Εικ. 1),

-της *εργασίας πάνω σε ένα ευρύτερο πλαίσιο γνώσης*, όπως π.χ. το Megalithic Portal (http://www.megalithic.co.uk/index.php) την ταυτοποίηση μεγαλιθικών μνημείων της Ευρώπης (Εικ. 2),

-της *συμπλήρωσης, συλλογής, της καταγραφής, της ταξινόμησης*, όπως π.χ. (α) του HyperCities (http://hypercities.ats.ucla.edu/), μια συνεργατική, εκπαιδευτική πλατφόρμα για ταξίδια πίσω στο χρόνο, για να εξερευνήσουν και να συμπληρώσουν οι χρήστες τα ιστορικά στρώματα των πόλεων σε ένα διαδραστικό περιβάλλον, (β) του HistoryPin (http://www.historypin.com/), όπου στην ουσία 'ξαναγράφεται' η παγκόσμια ιστορία με τη βοήθεια χρηστών, όπως αναφέρεται χαρακτηριστικά στην ιστοσελίδα (Εικ. 3), (γ) του προγράμματος Micropasts (http://micropasts.org/), μια πρωτοβουλία του Βρετανικού Μουσείου και του UCL Institute of Archaeology (http://www.ucl.ac.uk/news/news-articles/0414/160414-crowdsourcing-bronze-age), που μέσω μιας πλατφόρμας ανοιχτού κώδικα ζητάει από το κοινό να βοηθήσει στην καταλογογράφηση πάνω από 30.000 προϊστορικών αντικειμένων (Εικ. 4).



Εικόνα 1 Μεταγραφή ελληνικών παπύρων στο πρόγραμμα Ancient Lives. (http://www.ancientlives.org/transcribe)



Εικόνα 2 Ταυτοποίηση μνημείων, Megalithic Portal (http://www.megalithic.co.uk/index.php)

Εικόνα 3 Καταγραφή ιστορικών γεγονότων, HistoryPin (http://www.historypin.com/).

Εικόνα 4 Καταλογογράφηση αρχαιολογικών αντικειμένων Micropasts (http://micropasts.org/)

3. Παράγοντες παρακίνησης χρηστών *crowdsourcing*

Ποιοι άραγε είναι οι λόγοι που διαδικτυακοί εθελοντές εργάζονται δωρεάν και ορισμένες φορές εντατικά, '*σαν να πρόκειται για κανονική οκτάωρη πληρωμένη εργασία*'; Ο χρήστης μιας εφαρμογής crowdsourcing ικανοποιεί μια ανάγκη του, είτε κοινωνικής αναγνώρισης, αυτοεκτίμησης, είτε ανάπτυξης ατομικών ικανοτήτων (Estelles-Arollas and González-Ladrón-De-Guevara 2012). Στο πλαίσιο μιας αδημοσίευτης μεταδιδακτορικής έρευνας (Συλαίου 2013) εντοπίστηκαν οι βασικοί παράγοντες παρακίνησης για την αφιλοκερδή συμμετοχή χρηστών σε εφαρμογές crowdsourcing. Οι παράγοντες εσωτερικής παρακίνησης περιλαμβάνουν:

- την προσφορά στο κοινωνικό σύνολο,
- την περηφάνια που αισθάνεται για μια καλή πράξη,
- την εκτίμηση για τον πολιτιστικό οργανισμό και το έργο του,
- την απόλαυση που αντλείται από τέτοιου είδους εργασίες και την ψυχαγωγία,
- την ικανοποίηση,
- την ευχάριστη αξιοποίηση του ελεύθερου χρόνου,
- την εξέλιξη ατομικών δεξιοτήτων,
- την απόκτηση γνώσεων/ μάθηση για ένα συγκεκριμένο θέμα,
- την εξάσκηση της δημιουργικότητας,
- την ψυχαγωγία,
- το παιχνίδι,
- την αυτοπεποίθηση που αισθάνεται από την εργασία που ανέλαβε και διεκπεραίωσε.

Οι παράγοντες εξωτερικής παρακίνησης αφορούν κυρίως:

- για επαγγελματικούς λόγους, π.χ. την προώθηση σε επαγγελματικό επίπεδο,
- για κοινωνικές επαφές και συναναστροφές,
- για γνωριμία με ανθρώπους με κοινά ενδιαφέροντα,
- για συνεργασία με άλλους,
- για τη δημιουργία και συμμετοχή σε ψηφιακές κοινότητες ανθρώπων,
- για λόγους φήμης/ αναγνώριση,
- επειδή συμμετέχουν και φίλοι/οικογένεια.

Συνεπώς, οι βασικοί παράγοντες παρακίνησης των χρηστών crowdsourcing εφαρμογών θα μπορούσαν να κατηγοριοποιηθούν σε: (α) συναισθηματικούς, (β) εκπαιδευτικούς, (γ) κοινωνικούς και (δ) επαγγελματικούς λόγους.

4. Συζήτηση

Η χρήση εργαλείων του Web 2.0 στους ιστοχώρους πολιτιστικών οργανισμών ενθαρρύνει την αλληλοεπίδραση και την επικοινωνία των χρηστών τόσο μεταξύ τους, όσο και με τον ίδιο τον πολιτιστικό οργανισμό. Το αποτέλεσμα είναι ότι, σε αντίθεση με τη προηγούμενη «γενιά» του Παγκόσμιου Ιστού, δημιουργείται ένα συμμετοχικό, διαδραστικό περιβάλλον που επικεντρώνεται στην συνεργασία μέσω Διαδικτύου, στην αλληλεπίδραση, τη σύνδεση και την επικοινωνία με τους χρήστες.

Οι πολιτιστικοί οργανισμοί, και πιο συγκεκριμένα οι πινακοθήκες, οι βιβλιοθήκες, τα αρχεία και τα μουσεία, πειραματίζονται όλο και περισσότερο στον τομέα του crowdsourcing. Ο σκοπός τους είναι να αξιοποιήσουν την «ευφυΐα του πλήθους», να συνεργαστούν με ανώνυμους εθελοντές μέσω Διαδικτύου για να διεκπεραιώσουν εργασίες που δε θα μπορούσαν να χρηματοδοτήσουν και να προσλάβουν εργαζόμενους, για να τις υλοποιήσουν. Με αυτόν τον τρόπο δίνεται η δυνατότητα στους χρήστες-εθελοντές (α) να δηλώσουν την παρουσία τους στον κυβερνοχώρο, (β) να ανταποκριθούν στην πρόσκληση του πολιτιστικού οργανισμού, (γ) να προσφέρουν την εργασία τους –ατομικά ή/και ομαδικά– οργανώνοντας σε ορισμένες περιπτώσεις διαδικτυακές κοινότητες και (δ) να βοηθήσουν και να προωθήσουν την έννοια της συνεργασίας και της αλληλεγγύης, της ενεργητικής συμμετοχής και της κοινωνικής προσφοράς.

Η ηλεκτρονική συμμετοχή (e-Participation) μέσω του crowdsourcing ενισχύει την εξωστρέφεια των πολιτιστικών οργανισμών, παρέχει έναν απευθείας δίαυλο επικοινωνίας των εθελοντών με τους πολιτιστικούς οργανισμούς, ενώ παράλληλα ενδυναμώνει την μεταξύ τους σχέση. Η συμμετοχή των διαδικτυακών εθελοντών μπορεί να βοηθήσει τόσο στη βελτίωση διαδικασιών διαμόρφωσης πολιτικών των πολιτιστικών οργανισμών, όσο και στον καθορισμό στρατηγικής και σχεδιασμού, θέτοντας τους διαδικτυακούς εθελοντές συνδιαμορφωτές ατζέντας και κάνοντας πράξη την ηλεκτρονική Δημοκρατία (e-Democracy).

Όπως αναφέρθηκε και παραπάνω, η μετασχηματιστική δύναμη της καινοτομίας του crowdsourcing προσφέρει μια σειρά από λύσεις σε ορισμένα από τα οικονομικά αδιέξοδα των πολιτιστικών οργανισμών και επιτρέπει τη συμμετοχικότητα χωρίς αποκλεισμούς[1]. Επίσης, τους βοηθάει να γίνουν πιο ‘ανοικτοί’ και προσβάσιμοι από το κοινό τους, να προσφέρουν ελεύθερα και χωρίς περιορισμούς ψηφιοποιημένα δεδομένα, που παλιότερα αφορούσαν και προσφέρονταν προς επεξεργασία σε ειδικούς.

Ωστόσο, υπάρχουν μια σειρά από ζητήματα που προβληματίζουν και αποτελούν θέματα μελλοντικής έρευνας. Ένα από αυτά σχετίζεται με την στρατηγική υιοθέτηση του crowdsourcing από πολιτιστικούς οργανισμούς. Η Nina Simon (2007) δημιουργεί με βάση τον κανόνα 90-9-1 του Nielsen μια «ιεραρχία της κοινωνικής συμμετοχής», μια νέα πρόταση για ένα μοντέλο σχεδιασμού συμμετοχικών εμπειριών. Η μεθοδολογία σχεδιασμού για μουσεία που επιθυμούν να χρησιμοποιήσουν τεχνικές πληθοπορισμού στις γνωσιακές εμπειρίες που προσφέρουν, σύμφωνα με την έρευνα που παρήχθη από το COMMIT και το Πανεπιστήμιο Τεχνολογίας του Delft, πρέπει να κινηθεί σε τρία στάδια (Oosterman 2013):

1. *Προσδιορισμός στόχου*: διαδικασία κατά την οποία μελετάται το είδος της πληροφορίας που θα συλλεχθεί, αναλύονται οι κίνδυνοι, προσδιορίζεται το επιμέρους περιεχόμενο το οποίο θα εμπλουτισθεί και τα κριτήρια ποιότητας του μετα-περιεχομένου.

2. *Ταύτιση κοινότητας με στόχο*: προσδιορίζεται το είδος της κοινότητας που θα ικανοποιήσει τους στόχους που έχουν τεθεί στο πρώτο βήμα, σχεδιάζεται η επικοινωνιακή πολιτική για αυτή την κοινότητα, εκτελείται με στοχευμένο τρόπο η επικοινωνία για την επίτευξη της δραστηριότητας στα κανάλια που δρα η κοινότητα αυτή.

3. *Σχεδιασμός δραστηριότητας crowdsourcing*: δημιουργούνται οι ροές εργασίας των δραστηριοτήτων, κατανέμονται οι εργασίες, εκτελούνται οι εργασίες από την κοινότητα με την επιμέλεια, καθοδήγηση και συντονισμό του οργανισμού

Σε αυτά θα θέλαμε να προσθέσουμε δύο ακόμα στάδια, ένα στάδιο «βιωσιμότητας» και το στάδιο της «αξιολόγησης»:

4. *Βιωσιμότητα*: δημιουργούνται «σχέσεις» με την κοινότητα με τη μορφή επιβραβεύσεων και ενθαρρύνσεων. Επίσης χαρτογραφείται η κοινότητα και 'καλλιεργούνται' γειτονικές κοινότητες (ripple-effect) ενδιαφέροντος για μελλοντικά έργα crowdsourcing[2].

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[1] Τουλάχιστον σε ό,τι αφορά τους ανθρώπους που έχουν πρόσβαση στο Διαδίκτυο και είναι ψηφιακά εγγράμματοι.

[2] Έχει αναφερθεί ότι η εθελοντική προσφορά των ανθρώπων είναι ελεύθερη και δε μπαίνει σε περιορισμούς και πλαίσια. Κανείς δεν είναι σε θέση να προβλέψει πόσο μπορεί να διαρκέσει η διάθεση

5. *Αξιολόγηση*: μετά το πέρας της δραστηριότητας γίνεται ανάλυση της ποιότητας και ποσότητας του περιεχομένου, του βαθμού διάδρασης με την κοινότητα, η απήχηση/ το εκτόπισμα της δράσης στα κοινωνικά δίκτυα και το κόστος σε φόρτο εργασιών ελέγχου και έγκρισης (moderation) της ποιότητας από τον φορέα.

Επίσης, με δεδομένο ότι το ενδιαφέρον νέων διερευνήσεων μετατοπίζεται από τη μεθοδολογία («crowdsourcing») στο παραγόμενο αποτέλεσμα («crowd generated knowledge»), προτείνεται και ένα ακόμα στάδιο «μετα-τεκμηρίωσης». Ακόμη, καθώς η αξία των πολιτιστικών δεδομένων που διαχειρίζονται οι οργανισμοί μνήμης εμπλουτίζεται με την γνωσιακή επιμέλεια της κοινότητας ενδιαφέροντος σε αυτό, τα δεδομένα που παράγονται μέσω δράσεων crowdsourcing αποτελούν έναν όγκο μεταδεδομένων παραγόμενων όχι από τεκμηριωτές, αλλά από κοινότητες.

6. *Μετα-τεκμηρίωση*: τα μεταδεδομένα παραγόμενα από χρήστες με διαδικασίες crowdsourcing συλλέγονται και τεκμηριώνουν τις μουσειακές συλλογές μαζί με τα μεταδεδομένα που παράγουν οι ειδικοί του μουσείου.

Επομένως, οι νέες ερευνητικές κατευθύνσεις διερευνούν θέματα, όπως ο πολλαπλασιασμός ετικετών (tag propagation) και οι στρατηγικές εξόρυξης δεδομένων, που μπορούν να χρησιμοποιηθούν από μουσεία, για να μεγιστοποιηθούν δραστηριότητες κοινωνικής σημασιολογικής σήμανσης (social semantic labelling).

Επίσης, είναι σε εξέλιξη η έρευνα που αφορά την πρόσκληση πολιτών-ειδικών επιστημόνων (citizen scientists) για μια διαδικασία πιο συγκεκριμένου crowdsourcing, του niche-sourcing (Oosterman *et al.* 2014). Πιο συγκεκριμένα, κοινότητες ειδικών επιστημόνων καλούνται για να συμμετέχουν και να συμβάλουν σε διαδικασίες και εργασίες που αφορούν εμπεριστατωμένο σχολιασμό και υψηλής ποιότητας υπομνηματισμό (high quality annotations): (α) ενδιαφέρει όλο και περισσότερο, διότι αποφέρει μεταδεδομένα ποιότητας, που μπορούν να συλλεχθούν, (β) εμπλουτίζει τη μουσειακή τεκμηρίωση με δεδομένα ποιότητας που ενδεχομένως λείπουν και τελικά (γ) βοηθάει στη μετεξέλιξη της μουσειακής τεκμηρίωσης από Έργο Έντασης Πόρων, σε Έργο που απαιτεί Ένταση Γνώσης (ΕΕΓ) (knowledge intensive task), δηλαδή αποτελεσματική εμπλοκή του προσώπου σε ενέργειες που απαιτούν σε μεγάλο βαθμό γνώσεις.

Επιτυχημένα πειράματα τέτοιων Έργων Έντασης Γνώσης έχουν υλοποιήσει -κυρίως- μουσεία Φυσικής Ιστορίας και Επιστήμης, λόγω της διείσδυσης της εκλαϊκευμένης επιστήμης στο Διαδίκτυο. Ωστόσο, και μουσεία με συλλογές τέχνης πειραματίζονται σε διαθεματική τεκμηρίωση καλώντας κοινότητες πολιτών-ειδικών και χρησιμοποιώντας θησαυρούς και δομημένα λεξιλόγια από οργανισμούς ειδικών επιστημόνων. Για παράδειγμα, το Rijksmuseum κάλεσε λάτρεις των πουλιών να επισημάνουν εικόνες με πουλιά από τη συλλογή του χρησιμοποιώντας ονόματα πουλιών από ένα δομημένο λεξιλόγιο, το οποίο βρήκαν από την Παγκόσμια Ένωση Ορνιθολόγων (IOC World Bird List). Ενσωμάτωσαν το λεξιλόγιο της Ένωσης με δεδομένα της δικής τους συλλογής, το μετέτρεψαν σε RDF και κάλεσαν την κοινότητα να χρησιμοποιήσει τις ειδικές γνώσεις της για να αναγνωρίσει τα διάφορα είδη πουλιών σε έργα της συλλογής του Rijksmuseum (COMMIT-SEALINCMedia Rijksmuseum 2014).

Άλλα θέματα που συγκεντρώνουν ερευνητικό ενδιαφέρον είναι η μοντελοποίηση εμπιστοσύνης (trust modelling), η ενέργεια δηλαδή της βελτιστοποίησης διαδικασιών συλλογικής τεκμηρίωσης για την διασφάλιση ποιότητας τεκμηρίωσης, καθώς και της ελαχιστοποίησης κινδύνου (λαθών, ασάφειας ετικετών κλπ.[3]), ειδικά σε ό,τι αφορά το κομμάτι της προσθήκης ετικετών σε μουσειακό περιεχόμενο (tagging). Τέλος, διερευνώνται οι καλύτερες στρατηγικές σχεδιασμού εφαρμογών crowdsourcing και τα στοιχεία σχεδιασμού εμπειρίας χρήστη (UX) για την υλοποίηση καλύτερων πλατφορμών για τη διευκόλυνση της ενεργής εμπλοκής κοινοτήτων και

του κόσμου να βοηθήσει/εργαστεί αφιλοκερδώς, ενώ παράλληλα η ζήτηση για crowdsourcing ολοένα και αυξάνεται.

[3] Θέματα μελλοντικής έρευνας πρέπει να αποτελέσουν ζητήματα που αφορούν τη χρήση crowdsourcing από τους πολιτιστικούς οργανισμούς σε ό,τι αφορά εργασίες που μέχρι πρότινος γίνονταν από εξειδικευμένους επιστήμονες. Υπάρχουν, όμως, σοβαρά θέματα που αφορούν την ποιότητα και την αξιοπιστία των δεδομένων. Συχνά η ποσότητα των δεδομένων που παράγονται από τους χρήστες έχουν λάθη και δεν έχουν τα απαιτούμενα επίπεδα εγκυρότητας και αξιοπιστίας. Η αιτία είναι ότι συχνά οι χρήστες δε διαθέτουν τις εξειδικευμένες γνώσεις που απαιτούνται και η εκπαίδευση, η οποία τις περισσότερες φορές περιορίζεται σε ολιγόλεπτο εκπαιδευτικό video, δεν είναι επαρκής. Ένα ερώτημα που χρειάζεται απάντηση είναι αν η «ευφυΐα του πλήθους» είναι ικανή να υποκαταστήσει τις γνώσεις επιστημόνων που έχουν εξειδικευτεί για πολλά χρόνια σε συγκεκριμένα επιστημονικά πεδία και αντικείμενα. Για παράδειγμα πόσο ασφαλής είναι η ανάθεση επιλογής έργων από χρήστες για την έκθεση ενός μουσείου (co-curating);

της διαδικασίας προσθήκης ετικετών σε οπτικό περιεχόμενο (visual tagging).

Το crowdsourcing μπορεί να θεωρηθεί ως μια νέα μορφή φιλανθρωπίας και εθελοντισμού μέσω Διαδικτύου. Υπάρχουν πολλά περιθώρια αξιοποίησής του από τους πολιτιστικούς οργανισμούς, αλλά και εξέλιξης των σχετικών τεχνολογιών. Αναμένεται να αναπτυχθούν περισσότερες μέθοδοι και εργαλεία που θα επιτρέψουν την πλήρη αξιοποίηση της συμμετοχικής τάσης του Web 2.0, αλλά και της τάσης του Web 3.0 να συνδέσει ανθρώπους και εφαρμογές, να επιτρέψει την πρόσβαση σε κατανεμημένες βάσεις δεδομένων, μηχανική μάθηση / λογική, κ.ά. Επίσης, αναμένεται να αξιοποιήσει υπάρχουσες, αλλά και αναδυόμενες τεχνολογίες, όπως επαυξημένη πραγματικότητα (augmented reality), τα semantics, οι συμμετοχικές τεχνολογίες και τα κοινωνικά δίκτυα του Web 2.0, που μπορεί να εξελιχθούν σε γεωκοινωνικούς ιστούς (π.χ. Foursquare) και ιστούς επαυξημένης πραγματικότητας (π.χ. Layar) (Web 3.0, Γλωσσάρι Μονάδας Σημασιολογικού Ιστού ΑΠΘ).

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3D Modelling, Visualisation and Simulations

BREAKING POTS – SIMULATING DESIGN FAILURES OF TRANSPORT AMPHORAE BY USING THE FINITE ELEMENT METHOD (FEM)

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Περίληψη/ Abstract

Τα αγγεία που χρησιμοποιούνταν για τη μεταφορά ή την αποθήκευση προϊόντων, όπως για παράδειγμα οι εμπορικοί αμφορείς, έπρεπε να αντέχουν μεγάλα μηχανικά φορτία κατά τη διάρκεια της χρήσης τους. Η θραύση ενός αμφορέα προκαλούσε συνήθως την απώλεια του περιεχομένου του και συχνά έθετε σε κίνδυνο ολόκληρο το φορτίο. Η εργαστηριακή μελέτη των μηχανικών ιδιοτήτων του υλικού μπορεί να συμβάλλει στην μελέτη της συμπεριφοράς του αμφορέα. Η επίδραση του σχήματος όμως είναι πολύ περίπλοκη για να εξεταστεί πειραματικά. Για το λόγο αυτό αναπτύσσονται ψηφιακά μοντέλα και εξετάζονται με προσομοίωση των μηχανικών φορτίων χρησιμοποιώντας τη μέθοδο της ανάλυσης πεπερασμένων στοιχείων. Η προσέγγιση της προσομοίωσης θα αναπτυχθεί στην περίπτωση των Ελληνιστικών εμπορικών αμφορέων καθώς και τα θεωρούμενα μηχανικά φορτία που αναπτύσσονται κατά τη μεταφορά σε ένα εμπορικό πλοίο.

Ceramic vessels which were used for storage and transport of commodities, such as wine amphorae, had to withstand considerable loads during use. The failure of an amphora caused commonly the loss of the content and could potentially endanger the entire cargo. In order to test the performance of the amphorae the ceramic material can be tested for its mechanical properties. The influence of the vessel design, however, proved to be too complex to be tested in the laboratory. Therefore, digital models of ceramic bodies can be created and tested under simulated loads using the finite element method. The simulation approach is demonstrated with the example of Hellenistic wine amphorae and the assumed loads that they had to withstand during transport in a cargo ship.

Keywords: amphorae, mechanical loads, vessel design, FEM

Introduction

Utilitarian ceramics can be roughly divided in three classes according to their function: storage vessels, transport vessels and vessels or installations used for processing. Fabricated in order to fulfil different requirements the ceramics commonly presented different material properties adjusted to their specific use, such as flexural or compressive strength, toughness, permeability, heat capacity and thermal conductivity. These properties were controlled by the craftspeople by means of raw material selection, clay paste modification and firing conditions as it can be investigated by laboratory analyses.

Apart from the material properties, shape parameters may also affect the response of a vessel to mechanical or thermal loads. Such parameters can vary from size and wall thickness up to curvatures and ridges. Shape, in contrast to material properties, is more difficult to examine by material testing as it is more complex. Furthermore, these kinds of tests are commonly destructive. Therefore, testing of genuine archaeological objects is categorically impossible. Testing of replicates on the other hand introduces additional uncertainty in terms of level of details in comparison to the original material and accurateness of the copy. An alternative approach is the development of two- or three-dimensional computer models, taking into account the material properties. These models can be tested under simulated loads by using the finite element method (FEM) (Kilikoglou & Vekinis 2002, Senjanovic *et al.* 2004, Radic-Rossi 2005, Hein *et al.* 2008).

The present paper will introduce this simulation approach and demonstrate how it can be applied using the example of transport vessels. Transport vessels, such as amphorae, were built with specifications to be able to contain their content during transport from its place of production to its place of consumption. The failure of transport vessels commonly caused loss of the content and under certain circumstances, besides the contents themselves, they could endanger the stability of the entire cargo for example during marine trade.

1. The FEM approach

The response of an object to external loads is a boundary value problem. The displacement subject to mechanical loads for example can be described with partial differential equations with explicit boundary conditions. These are commonly not trivial to solve, particularly if the system is examined in two or three dimensions and if complex shapes are considered. In the FEM approach the boundary value problem is transferred into a system of discrete variational equations, which can be solved and provide an approximation to the total solution (Hughes 2000). Therefore, the region of interest, such as a ceramic object, is divided in an arbitrary number of sub-regions, the so-called elements. In this way the continuous structure is mapped on a discrete mesh. The elements can be very small, which increases the accuracy of the evaluation but at the same time their quantity and eventually the computing time. Still, their size is finite as is their number. Each element consists of a group of nodes connected among each other. For each of these nodes basis functions are defined concerning the degrees of freedom (DOF) to be examined, such as coordinates or temperature. These functions build an equation system which can be solved under consideration of the external loads and constraints. Dynamic or so-called transient problems are solved by calculating solutions in discrete time intervals.

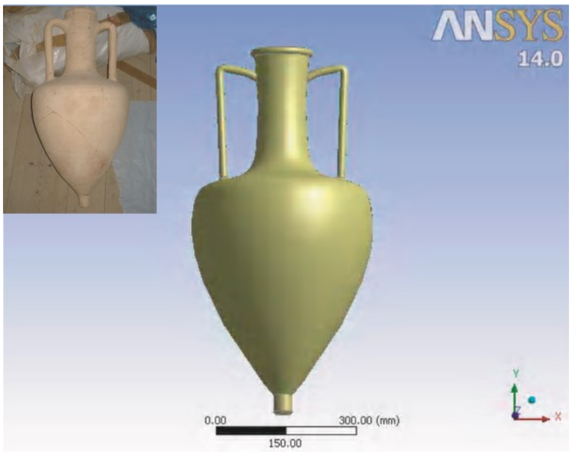

Figure 1 Creation of a digital model of a Rhodian amphora from photograph

The first step of the simulation is to create a digital model of the object, for example an amphora. This can be done on the basis of photographs or sketches, from which the profile of the vessel is extracted. The profile is revolved afterwards around the y-axis in order to obtain a rotationally symmetric digital body to which a specific wall thickness is applied (Fig. 1). Handles are modelled separately and merged with the amphora body. More realistic models can be generated by application of a 3D scanner (Karasik & Smilanski 2008). In this way also deviations from the rotational symmetry or variations of the wall thickness are considered. For a general assessment of design features, however, the development of the body from a profile is better suited. In the next step material properties of the ceramics, such as Young's modulus, Poisson ratio and density, are attributed to the digital model. These are determined by material testing either of vessel fragments or replicates of the ceramics, taking in account parameters, such as clay type, temper materials or firing conditions. Afterwards the model is meshed. The mesh size affects the closeness of the model to the true problem as the FEM solution eventually is an approximation. Particularly in areas, in which large stress or strain is expected, the mesh size has to be sufficiently fine, while the mesh size in other areas can remain coarse in order to reduce the element number and the required computing capacity.

Finally the constraints are defined. In the case of examining mechanical loads the constraints are usually displacement or anchoring of certain points, areas or regions and loads on other points, areas or regions. After the system is set up completely it can be solved by the computer. The solution provides the displacement of the nodes under different types of loads, from which stress or strain in specific areas are extracted. Through comparison with the fracture strength of the ceramics critical loads can be estimated and their relation to the vessel design can be examined (Hein *et al.* 2008).

2. Simulation of packing of transport amphorae

During the use of a transport amphora the probably most critical phase was the storage and transport in a cargo ship, in which amphorae commonly were piled up in layers (Twede 2002). Evidence from shipwrecks has revealed that the amphorae were packed in such a way that the bases of an overlying layer were fitted into the spaces between the shoulders of the lower layer. The computer simulation demonstrates that assuming tetragonal alignment of the amphorae within a layer each amphora had four contact areas on its shoulder with amphorae of the upper layer and four contact areas with amphorae of the lower layer (Fig. 2).

Even though the considered weight loads are actually static the solution of the problem has to be set up in time steps as the contact area is expected to increase with the load. In order to reduce the problem use of symmetries can be made so that eventually only one contact is evaluated, as indicated in Figure 2.

Figure 3 presents the simulated development of the contact area with increasing load, for the case of Rhodian amphorae with a wall thickness of 8mm assuming frictionless contact. The contact area at a maximum load of 1000N is c. 23.5 mm^2. This corresponds to a circle with a diameter of c. 5.5 mm, even though the contact area is rather oval. The strain distribution indicates pressure at the immediate contact area and maximum tension at the internal surfaces of the amphorae opposite the contact area (Fig. 4). Apart from this, increased tension is also indicated at the external surface in a distance of c. 2 mm around the contact area. The tension in the upper amphora produces a strain of c. 0.17%, which appears to be higher than in the lower amphora and actually it exceeds the critical strain of 0.11 %, which is estimated for this type of ceramics (Hein *et al.* 2008). Therefore, according to this simulation a failure of the amphora would be likely if the load on every contact point would indeed reach 1000N.

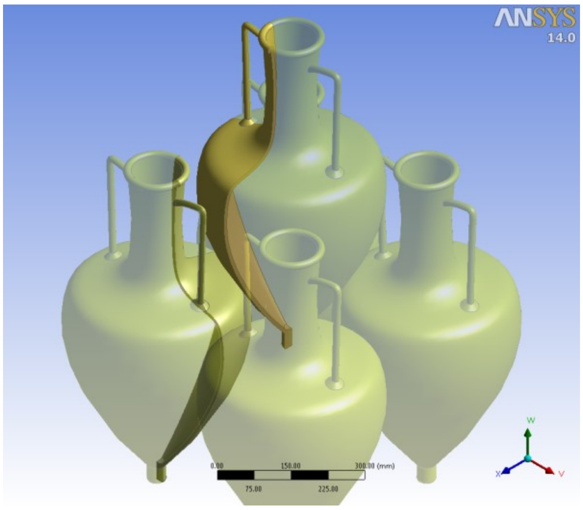

Figure 2 Amphora of the upper layer is placed between the shoulders of amphorae in the lower layer. For the solution symmetries are used to reduce the problem.

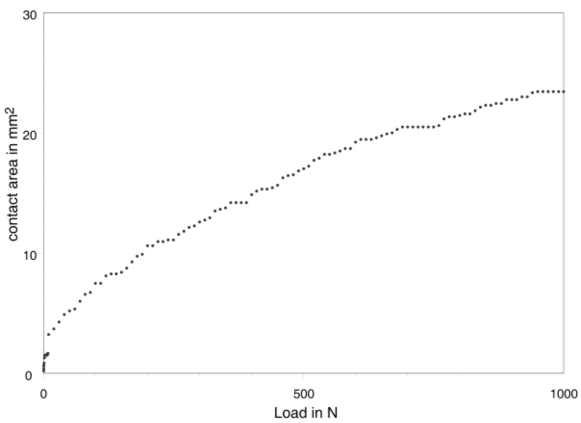

Figure 3 Development of the contact area with increasing load.

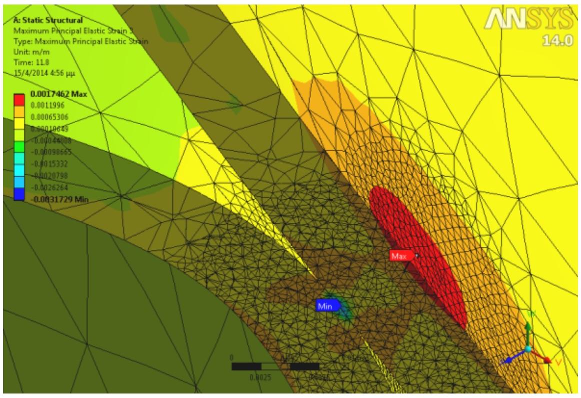

Figure 4 Simulated strain distribution in the two Rhodian amphorae with a load of 1000N. Presented is a section through the contact area.

In a more realistic simulation friction should be considered. In this case, however, a new parameter, the friction coefficient, has to be estimated, introducing a further uncertainty into the model and affecting at the same time the simulation results. An alternative way is actually to simplify the model, assuming bonded contacts. In this case nodes of the two amphorae, once they are in contact, will not move against each other. The resulting contact area is considerably larger than in the case of frictionless contact (Fig. 5), but the maximum strain, on the other hand, is reduced to 0.04%. Contact area and maximum strain, however, depend on the so-called pinball region, which defines the distance between two nodes, at which these are considered to be in contact.

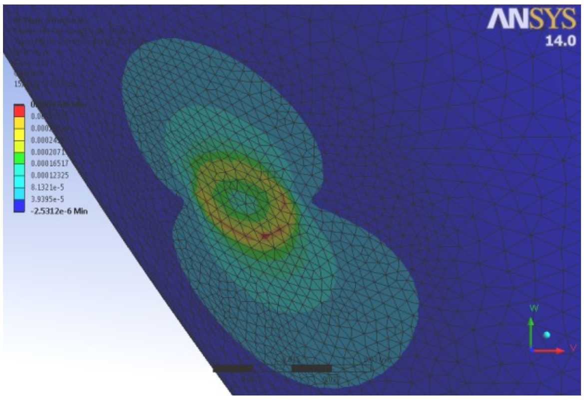

Figure 5 Strain distribution in the body of the upper amphora. The contact is assumed to be bonded.

A comparison of the simulation results (Fig. 4, 5) with actually failed vessels (Fig. 6) demonstrates that the model is realistic. As for the size of the damaged area the approach assuming bonded contact provides results, which are closer to the observed damages in comparison to assumed frictionless contact. In order to achieve more realistic results parameters such as friction coefficients or pinball region have to be adapted to the examined material.

Therefore, probably experiments will be necessary in order to refine the models.

Figure 6 Damaged amphora with a kidney shaped hole in its body.

In general, the application of FEM in archaeological studies, simulating structural and mechanical behaviour of objects, certainly has a large potential. Published studies, however, are still relatively rare. Apart from case studies on ceramic transport vessels structural FEM studies concern mainly architectural models (Levy & Dawson 2009) or ships (Foecke *et al.* 2010). FEM on the other hand can also be applied to simulate the thermal behaviour of ancient objects or structures (Hein & Kilikoglou 2007).

Conclusions

The FEM approach can be applied for examining the relation of vessel shape to the mechanical behaviour of transport amphorae under simulated loads. In this way different design parameters can be assessed in terms of their functionality.

As it was demonstrated simulations can contribute to the interpretation of failures and damages observed in archaeological vessels. However, in order to refine the models for example by introducing simulation parameters for frictional contact, it appears that experiments will be necessary.

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Η ΤΡΙΣΔΙΑΣΤΑΤΗ ΑΝΑΠΑΡΑΣΤΑΣΗ ΤΟΥ ΨΕΥΔΟΔΙΠΤΕΡΟΥ ΙΩΝΙΚΟΥ ΝΑΟΥ ΤΟΥ ΜΕΣΣΟΥ ΣΤΗ ΛΕΣΒΟ ΩΣ ΕΡΓΑΛΕΙΟ ΜΕΛΕΤΗΣ ΑΡΧΙΤΕΚΤΟΝΙΚΩΝ/ΑΡΧΑΙΟΛΟΓΙΚΩΝ ΔΕΔΟΜΕΝΩΝ ΣΕ ΨΗΦΙΑΚΟ ΠΕΡΙΒΑΛΛΟΝ

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Περίληψη/ Abstract

Το παρόν άρθρο εξετάζει τη συνεισφορά των τρισδιάστατων ψηφιακών αναπαραστάσεων στο χώρο της αρχαιολογίας. Ως παράδειγμα χρησιμοποιείται ο υστεροκλασικός ιωνικός ψευδοδίπτερος ναός του Δία, της Ήρας και του Διονύσου στην περιοχή Μέσσα της Λέσβου. Επιπλέον, εξετάζονται θεωρητικά και μεθοδολογικά θέματα που σχετίζονται με την επιστημονική αναπαράσταση αρχαιολογικών μνημείων, όπως η «καθαρότητα» της πληροφορίας, η ερμηνεία και η αξιολόγηση των δεδομένων μιας αναπαράστασης, οι διαφορετικές μορφές αναπαράστασης και τελικά η αξία των εικονικών αναπαραστάσεων ως ερευνητικό και ερμηνευτικό εργαλείο κατανόησης του παρελθόντος και των υλικών του καταλοίπων.

Our paper explores the contribution of three-dimensional, computer visualisation in the field of archaeology. The Ionic pseudo-dipteral temple of Zeus, Hera and Dionysus of the second half of the 4th century BC at Messa on the island of Lesvos is used as the case study of this research. Moreover, we touch upon theoretical and methodological aspects related explicitly to the scientific representation of monuments, i.e. the definition of the primary archaeological data, the ‘clarity’ of the archaeological information provided, the interpretation and the evaluation of a digital representation’s data, the different kinds of digital representations, and finally, the value of digital representations as a research and interpretative tool for the apprehension of the past and the material remains.

Λέξεις Κλειδιά: Εικονική Αρχαιολογία, Τρισδιάστατες ερευνητικές αναπαραστάσεις μνημείων, Αρχιτεκτονική μελέτη, Ψευδοδίπτερος ιωνικός ναός, Λέσβος

Εισαγωγή

Είναι γενικά παραδεκτό ότι τα μοντέλα (αναλογικά ή ψηφιακά) και η σύνθετη διαδικασία κατασκευής τους είναι θεμελιώδη στην αρχαιολογική ερμηνεία, με μακρά ήδη παράδοση. Εξαιτίας του ότι το παρελθόν είναι περίπλοκο, συχνά ακατάληπτο και ανεπαλήθευτο, η εργασία με φωτορεαλιστικά ψηφιακά μοντέλα μπορεί να οδηγήσει έναν μελετητή στην κατανόηση σύνθετων αρχιτεκτονικών και αρχαιολογικών θεμάτων (Sanders 1999, Chalmers & Stoddart 1996).

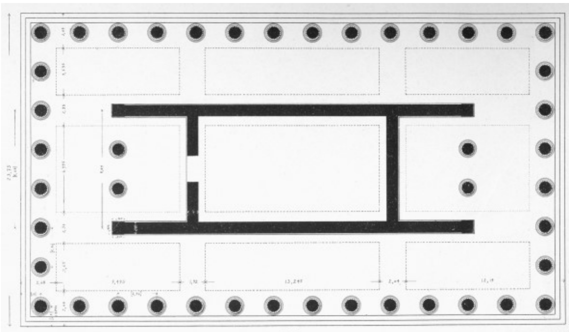
1. Το Ιερό του Μέσσου

Το Ιερό του Μέσσου αποτελεί έναν από τους σημαντικότερους αρχαιολογικούς χώρους της Λέσβου με ιδιαίτερη συμβολική αξία (Αχειλαρά 2004, 14). Σύμφωνα με την αρχαία παράδοση, βρισκόταν στο κέντρο του νησιού και αποτελούσε παλλεσβιακό Ιερό, ήδη από την αρχαϊκή εποχή με υπαίθρια βωμική λατρεία στους «αθάνατους Μάκαρες» (Treu 1958, 237, Treu 1963, 142–144, Robert 1960, 292,300, Αχειλαρά 2004, 20).

Στο Ιερό βρήκαν καταφύγιο ο Αλκαίος και η Σαπφώ λόγω της αντίδρασής τους στους τυράννους της Λέσβου, ενώ ο Θεόφραστος φαντάζεται τη Σαπφώ να συνοδεύει με τη λύρα της τα κορίτσια της Λέσβου σε επίσημους αγώνες, που τελούνταν στον ίδιο χώρο (Αθήναιος, *Δειπνοσοφισταί*, XIII 610a). Στις αρχές του 2ου αι. π.Χ. αποτέλεσε την έδρα του «Κοινού των Λεσβίων», μίας Ομοσπονδίας δηλαδή των πόλεων-κρατών της Λέσβου, όπου οι εκπρόσωποί τους συνεδρίαζαν προκειμένου να λάβουν αποφάσεις για κοινά στρατιωτικά, πολιτικά, θρησκευτικά και δικαστικά θέματα. Το «Κοινό» διατηρήθηκε με διαλείμματα, κυρίως λόγω της εναλλαγής των σχέσεων της Λέσβου με τη Ρώμη, έως το 2ο αι. μ.Χ. (Labarre 1992, 53, σημειώσεις 111–115, Κουρτζέλλης 2012, 313–315).

Το Ιερό ήταν αφιερωμένο στη λεγόμενη «Λεσβιακή Τριάδα» (Δίας, Ήρα και Διόνυσος). Στα τέλη του

4ου αι. π.Χ. οι πέντε πόλεις της Λέσβου αποφάσισαν την από κοινού χρηματοδότηση και ανέγερση ενός υπέρλαμπρου ψευδοδίπτερου ναού (Αχειλαρά 2004, 50, Κουρτζέλλης 2012, 314, σημ. 788), ο οποίος αντικατέστησε και ενσωμάτωσε στο εσωτερικό του ένα επίμηκες αρχαϊκό λατρευτικό κτίριο (Koldewey 1890, 48). Η επιλογή της ψευδοδίπτερης κάτοψης για το ναό της Λέσβου (Εικ. 1) αποτελεί την πρώτη γνωστή εφαρμογή της σε ιωνικούς ναούς, αλλά ταυτόχρονα αποτελεί και ένα μυστήριο της αρχαίας αρχιτεκτονικής: ο Βιτρούβιος αναφέρει ότι ο Ερμογένης είναι ο αρχιτέκτονας που «εφηύρε» τον ψευδοδίπτερο ναό (ΙΙΙ.3.1–10). Η ακριβής χρονολόγηση της δράσης του είναι επίσης υπό συζήτηση, αλλά πλέον πιστεύεται ότι εργαζόταν κατά τον 2ο αι. π.Χ. και πιθανότατα γύρω στο 150 π.Χ. (Pollitt 2000, 304 και σημ. 8 στη σελίδα 395, Gruben 2000, 433–434).



Εικόνα 1 Κάτοψη του υστεροκλασικού ψευδοδίπτερου ναού του Μέσσου (Koldewey 1890, pl. 20.2).

Σύμφωνα με τους παραπάνω μελετητές, η απόδοση της επινόησης της ψευδοδίπτερης μορφής στον Ερμογένη, δεν είναι απολύτως αποδεκτή, επειδή παρόμοιο τύπο κάτοψης είχαν οι σικελικοί δωρικοί ναοί ήδη από την αρχαϊκή εποχή («Ναός G» στο Σελινούντα, Ναός της Ήρας Λακινίας (450 π.Χ.) και στο «Ναό Β» στον Ακράγαντα (Olympieum) μόνο στις μακρές πλευρές (Pollitt 2000, 304, Gruben 2000, 337, εικ. 248). Επιπλέον, παρόμοια διαμόρφωση παρατηρείται και στον τεράστιο ψευδοδίπτερο, στα πλευρικά πτερά, ναό της Αρτέμιδος-Κυβέλης του 300 π.Χ. στις Σάρδεις (Dinsmoor 1950, 274, Μπακαλάκης 1990, 66, εικ. 30) και στον χρονολογούμενο στο α΄ τέταρτο του 6ου αι., σχεδόν ψευδοδίπτερο διπλό «εν παραστάσει» δωρικό ναό της Αρτέμιδος στην Κέρκυρα με 8Χ17 κίονες (Κοκκορού - Αλευρά 1995, 64, εικ. 47 και σημείωση 148 στο Labarre 1992, 67 με βιβλιογραφία για τα παραπάνω μνημεία). Ο αρχιτέκτονας των ψευδοδίπτερων ναών του Μέσσου και του ναού του Σμινθέου Απόλλωνα στη Χρύση της Τρωάδας ήταν κάποιος σύγχρονος του Πυθεού, ο οποίος έδρασε στα τέλη του 4ου αι. π.Χ. Η ερμηνεία, που προτείνεται για την αναφορά του Βιτρουβίου είναι ότι, ίσως ο Ερμογένης ήταν ο πρώτος που εφάρμοσε αυτό το είδος κάτοψης στον ιωνικό ρυθμό και πιθανότατα ο πρώτος που αιτιολόγησε γραπτώς τη χρήση της (Εικ. 2).

Εικόνα 2 Αναπαράσταση της όψης των στενών πλευρών του ναού (Koldewey 1890, pl. 20.1).

Ο επιβλητικός ναός διατηρήθηκε περίπου μέχρι τον 3ο αι. μ.Χ., όταν καταστρέφεται από σεισμό. Τον 4ο αι. η λάμψη της νέας θρησκείας και η ερειπιότητα του αρχαίου ναού επέτρεψαν τη μεταβολή του Ιερού σε εργαστηριακό χώρο, όπως υποδεικνύει η εύρεση οκτώ κλιβάνων σε επαφή και περιμετρικά του μνημείου. Στα τοιχώματά τους εντοπίστηκαν θραυσμένα αρχιτεκτονικά μέλη του ναού, ενώ στο εσωτερικό τους ασβεστοποιήθηκαν εκατοντάδες άλλα (Εικ. 3). Τον 5ο ή τον 6ο αι. μ.Χ. πάνω στη θεμελίωσή του κατασκευάστηκε μία τρίκλιτη παλαιοχριστιανική κοιμητηριακή βασιλική, από την οποία σώζονται λείψανα, κυρίως η αψίδα του κεντρικού κλίτους στα ανατολικά και θραύσματα από τις εσωτερικές κιονοστοιχίες (αρράβδωτοι σφόνδυλοι, κιονόκρανα), τμήματα θωρακίων και θραύσματα από το φράγμα του πρεσβυτερίου (Koldewey 1890, 48, πιν. 19 με λευκό χρώμα). Ο ναός πρόσφερε έτοιμο οικοδομικό υλικό για την ανέγερση της βασιλικής. Με το πέρασμα του χρόνου, ο ναός ξεχνιέται, τα αρχιτεκτονικά του μέλη θάβονται ή μετακινούνται για την κατασκευή άλλων κτιρίων/αναλημματικών τοίχων στην ευρύτερη περιοχή, όπως στο μεσαιωνικό χωριό στα δυτικά του Ιερού (Πετράκος 1967, 96). Η βασιλική επίσης καταστρέφεται και στη μεταβυζαντινή εποχή κατασκευάζεται στη θέση της ένα μικρότερο μονόχωρο εκκλησίδιο, το οποίο είναι γνωστό από τις πηγές ως ναΐσκος αφιερωμένος στον «Ταξιάρχη Μιχαήλ» (Koldewey 1890, 48, Κουρτζέλλης 2004, 78–79). Η αρπαγή και η επαναχρησιμοποίηση αρχιτεκτονικού υλικού θα είναι συνεχής ως τη νεώτερη εποχή, μέχρι την κήρυξη και προστασία του αρχαιολογικού χώρου από την τοπική Αρχαιολογική Υπηρεσία.

2. Η ανακάλυψη του μνημείου και οι ανασκαφικές έρευνες

Στα μέσα του 19ου αι. ο ναός αναφέρεται για πρώτη φορά από τον Γάλλο περιηγητή Boutan. Το 1885–1886 ο Γερμανός αρχιτέκτονας R. Koldewey ανασκάπτει το ναό, σχεδόν κατά το ήμισυ, και παρουσιάζει τα αρχιτεκτονικά στοιχεία του σε μία υποδειγματική δημοσίευση, η οποία περιλαμβάνεται στη μελέτη του με τίτλο *Die antiken Baureste der Insel Lesbos* (1890, 47–61, πιν. 18–26). Κατά τη διάρκεια του 20ου αι. γίνονται μικρής έκτασης ανασκαφικές έρευνες, με κυριότερη αυτή του Βασίλειου Πετράκου στα 1967–1968 (Πετράκος 1967, 96–102, πιν. 74–84, Πετράκος 1968, 84–86).

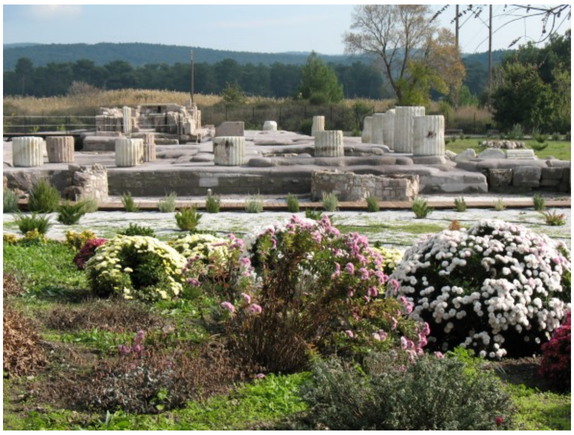
Το μνημείο θα αποκαλυφθεί πλήρως σε όλες του τις διαστάσεις μόλις το 1996. Κατά την περίοδο 2002–2004 θα πραγματοποιηθεί η διαμόρφωση του σε επισκέψιμο αρχαιολογικό χώρο με χρηματοδότηση του ΠΕΠ Βορείου Αιγαίου (Εικ. 4). Οι τελευταίες εργασίες έφεραν στο φως ένα σπουδαίο ερευνητικό υλικό, ικανό να φωτίσει άγνωστα στοιχεία της αρχιτεκτονικής του μνημείου (Αχειλαρά 2004, Κουρτζέλλης 2004).

Εικόνα 3 Θραύσματα ιωνικών κιονοκράνων των κιόνων του πτερού. Διακρίνονται οι έλικες και η διακόσμηση των προσκεφαλαίων (Αχειλαρά 2004).

3. Η κατάσταση διατήρησης του μνημείου και η δυσκολία κατανόησής του

Σήμερα ο ναός σώζεται στο ύψος της θεμελίωσής του, καθιστώντας δύσκολη την «ανάγνωσή» του. Από την τριβαθμιδωτή κρηπίδα σώζονται ελάχιστοι λίθοι στα δυτικά (εξωτερικό μέτωπο) και μερικές εσωτερικές στρώσεις στα νοτιοανατολικά του εκκλησιδίου (Κουρτζέλλης 2004, 43–47, Αχειλαρά 2004, 26–30).

Μνημεία που διατηρούνται στο επίπεδο της θεμελίωσης, όπως ο υστεροκλασικός ναός του Μέσσου, μνημεία που παρουσιάζουν ποικίλες επεμβάσεις, αλλαγές χρήσης και προσθήκες ανά τους αιώνες, είναι δύσκολο να γίνουν κατανοητά στους επισκέπτες, αλλά ακόμη και σε ειδικούς επιστήμονες που δεν έχουν ασχοληθεί με το ίδιο το μνημείο. Στην περίπτωση αυτή οι επιστήμονες έχουν στη διάθεσή τους μία σειρά οπτικών εργαλείων, προκειμένου να παρουσιάζουν την αρχική μορφή ενός μνημείου ή κάποια σημαντικά στοιχεία της αρχιτεκτονικής του. Τα εργαλεία αυτά είναι κυρίως οι σχεδιαστικές απεικονίσεις (κατόψεις, όψεις, τομές), τα αναλογικά μοντέλα υπό κλίμακα (*scale-models* ή *plaster-models*), οι αναλογικές αναπαραστάσεις κ.α. Σε πολλές περιπτώσεις επιλέγεται η χρήση των ψηφιακών μοντέλων ως το πιο κατάλληλο μέσο για την παρουσίαση των ανασκαφικών δεδομένων (Εικ. 5, Κουρτζέλλης 2012, 262–263).



Εικόνα 4 Ο αρχαιολογικός χώρος μετά τις εργασίες διαμόρφωσης και ανάδειξης (Κουρτζέλλης 2004).

Εικόνα 5 Ψηφιακή τρισδιάστατη αναπαράσταση ανάγλυφης φυτικής διακόσμησης προσκεφαλαίου κιονοκράνου σε ανάπτυγμα (Κουρτζέλλης 2012).

Οι σχετικές Χάρτες παρέχουν άμεση ή έμμεση στήριξη στη χρήση των *Νέων Τεχνολογιών* στον τομέα του Πολιτισμού. Ενδεικτικά αναφέρουμε τη *Χάρτα του Πολιτισμικού Τουρισμού* (στη συνέχεια ICOMOS 1999), τη *Σύμβαση για την προστασία της Αρχιτεκτονικής Κληρονομιάς της Ευρώπης* (στη συνέχεια Convention 1985), τη *Χάρτα της Βενετίας*, τη *Χάρτα ICOMOS για την ερμηνεία και την παρουσίαση των χώρων της πολιτιστικής κληρονομιάς*, τη *Χάρτα του Ename*, στην πρώτη διατύπωσή της το 2002, τη *Χάρτα του Λονδίνου* 2.1, Φεβρουάριος 2009 (αναλυτική διαπραγμάτευση στο Κουρτζέλλης 2012, 57–68) και τη *Χάρτα της Σεβίλλης για την Εικονική Αρχαιολογία* (Ιούλιος 2010 και Forum Draft 2011).

4. Σκοπός της εικονικής αναπαράστασης

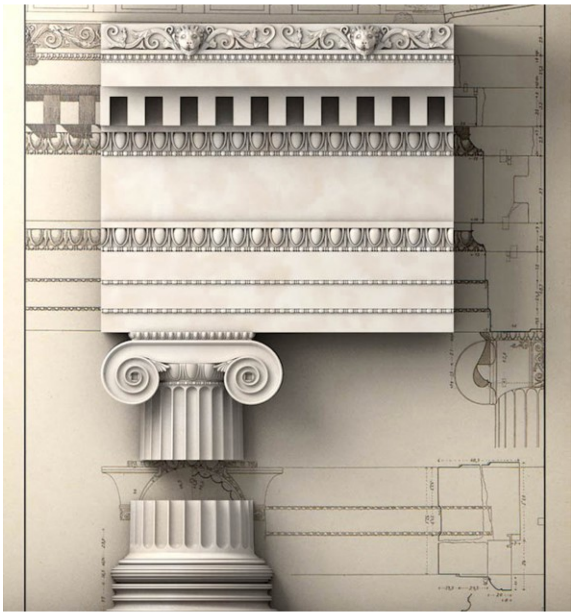
Σκοπός της εικονικής αναπαράστασης ήταν πρωτίστως η αρχιτεκτονική μελέτη του μνημείου με την κατασκευή αναλυτικών ψηφιακών μοντέλων για κάθε ένα αρχιτεκτονικό στοιχείο του.

Η μελέτη ενός μνημείου σε ψηφιακό περιβάλλον παρέχει τη δυνατότητα στους μελετητές να αξιοποιήσουν όλες τις διαθέσιμες πληροφορίες, τα αναλογικά σχέδια και τις αναπαραστάσεις και να οπτικοποιήσουν προτάσεις/θεωρίες και περιγραφές, χωρίς να επηρεάζεται το ίδιο (Frischer *et al.* 2002, 11). Ειδικά για μνημεία, τα οποία ανασκάπτονται για μεγάλα χρονικά διαστήματα και διαθέτουν ασύνδετες πληροφορίες διαφορετικών μελετητών η ψηφιακή τεχνολογία είναι ιδιαίτερα χρήσιμη, καθώς μπορεί να «ενώνει» δεδομένα. Με τη δημιουργία αναλυτικών ψηφιακών μοντέλων οι αρχαιολόγοι μπορούν να ανασκάψουν εκ νέου έναν χώρο, να θέσουν ερωτήματα και να οπτικοποιήσουν τις ενδείξεις που έχουν καταγράψει.

Η έννοια του «εικονικού» (*Virtual*) δηλώνει ότι πρόκειται για ένα αντίγραφο, ένα υποκατάστατο, που στις περισσότερες περιπτώσεις αναπαριστά κάτι που πλέον δεν υπάρχει στην εποχή μας, αλλά υπήρξε στο παρελθόν (Reilly 1991, 133–140, Reilly 1992, 162).
Ο σκοπός της δημιουργίας του μοντέλου ενός μνημείου είναι να επιτρέψει στους μελετητές να κατανοήσουν καλύτερα τη δομή, τη γεωμετρία του και ταυτόχρονα να λειτουργήσει ως κατάλληλος φορέας για πειραματισμούς με την πρόσθεση ή την αφαίρεση δομικών ή υφολογικών χαρακτηριστικών (Fishwick 1995, Mortenson 1985).

Για την ψηφιακή αναπαράσταση του υστεροκλασικού ναού χρησιμοποιήθηκε ως βασικό υλικό τεκμηρίωσης η αρχική μελέτη του R. Koldewey, η οποία μετά από έλεγχο αποδείχθηκε ακριβής στο μεγαλύτερο μέρος της (Εικ. 6), οι έρευνες των νεώτερων Ελλήνων μελετητών, η σχεδιαστική απεικόνιση (1:20 για τα οικοδομικά λείψανα και 1:10, 1:5 για τα θραύσματα), η φωτογραφική τεκμηρίωση, η ιδιαίτερη τεκμηρίωση του αρχιτεκτονικού υλικού, το οποίο τοποθετήθηκε στον ημιυπαίθριο εκθεσιακό χώρο της αρχαιολογικής θέσης, οι αναλυτικές μετρήσεις αρχιτεκτονικών μελών κ.α. Για την κατασκευή του μοντέλου χρησιμοποιήθηκαν μόνο *passive techniques* μέθοδοι μοντελοποίησης, ώστε να αποδοθεί πιστότερα η γεωμετρία κάθε αρχιτεκτονικού μέλους και να προκύψει ένα εύκολα διαχειρίσιμο αρχείο από έναν προσωπικό υπολογιστή (Κουρτζέλλης 2012, 329–370).

Για την ψηφιακή τρισδιάστατη απεικόνιση του ναού αξιοποιήθηκαν επιπλέον οι πληροφορίες που προέκυψαν από τη μελέτη κτιρίων, τα οποία παρουσιάζουν ομοιότητες με το ναό του Μέσσου, όπως ο ναός της Πολιάδος Αθηνάς στην Πριήνη, ο ναός της Αρτέμιδος Λευκοφρυηνής στη Μαγνησία επί Μαιάνδρῳ, το Μαυσωλείο της Αλικαρνασσού, ο ναός της Αθηνάς στην Πέργαμο, ο ναός του Διονύσου στην Τέω, το Διδυμαίο και κυρίως ο ναός του Απόλλωνα Σμινθέως στη Χρύση της Τρωάδας (Κουρτζέλλης 2012, 318–328, με αναλυτική περιγραφή και βιβλιογραφία για κάθε ένα από τα μνημεία που αναφέρονται παραπάνω).



Εικόνα 6 Διαδικασία ελέγχου της ψηφιακής αναπαράστασης με βάση τη μελέτη του Koldewey (Κουρτζέλλης 2012).

Για την κατασκευή των ψηφιακών μοντέλων επιλέχθηκε η χρήση του προγράμματος τρισδιάστατων γραφικών Cinema 4D (Release 13), το οποίο παρέχει τις απαραίτητες δυνατότητες μοντελοποίησης, κατασκευής υφών, ρεαλιστικής απόδοσης του γεωγραφικού αναγλύφου και προσομοίωσης των συνθηκών φωτισμού και κίνησης. Η επεξεργασία των υφών (textures) έγινε με το λογισμικό επεξεργασίας εικόνων Photoshop (Version CS5), καθώς και με την εφαρμογή που διατίθεται ενσωματωμένη στο Cinema 4D για την κατασκευή ψηφιακών υφών.

Στο πλαίσιο της εικονικής αναπαράστασης οφείλουμε να παρουσιάσουμε όλα τα αρχιτεκτονικά στοιχεία, έστω συμβατικά, ακόμη και αυτά για τα οποία υπάρχει ελλιπής ή μηδαμινή πληροφορία. Η απόδοση όλων των στοιχείων πρέπει να σέβεται τις αρχές της «Εικονικής Αρχαιολογίας», δηλαδή την αυστηρή και ρητή δήλωση όλων των πληροφοριών άμεσων ή έμμεσων, οι οποίες χρησιμοποιήθηκαν (Hermon 2008, 36–45). Η οπτικοποίηση των απόψεων/θεωριών σε ψηφιακό περιβάλλον είναι ιδιαίτερα σημαντική, καθώς μπορεί να επιβεβαιώσει, να απορρίψει ή να βοηθήσει στην επανεξέταση θεμάτων, συμβάλλοντας στην περαιτέρω έρευνα (Ryan & Roberts 1997, Κουρτζέλλης 2008, 87–94, Mealing 1992, Κουρτζέλλης 2012, 47–52).

5. Τα τρισδιάστατα ψηφιακά μοντέλα ως ερμηνευτικά εργαλεία στην αρχαιολογική επιστήμη

Τα μοντέλα αποτελούν απλοποίηση των σκέψεων ή των παραμέτρων μιας σύνθετης πραγματικότητας, όπως οι αρχαίοι ναοί (Lock 2003, 147). Επίσης ένα ψηφιακό ερευνητικό μοντέλο μπορεί να αναλυθεί περαιτέρω σε τέσσερις βασικές μορφές, οι οποίες καλύπτουν όλα τα είδη αναπαράστασης: 1) πραγματικό μοντέλο, 2) μοντέλο της σύγχρονης κατάστασης ενός μνημείου, 3) μοντέλο αποκατάστασης και 4) μοντέλο αναπαράστασης (Frischer & Stinson 2007, 51–52).

Τα λογισμικά τρισδιάστατης απεικόνισης πληροφοριών έχουν δύο βασικές χρήσεις στην επιστήμη της αρχαιολογίας: την ερμηνευτική (*interpretive*) και την εκφραστική (*expressive*). Τα ερμηνευτικά εργαλεία βοηθούν τους επιστήμονες να δουν και να επεξεργαστούν την οπτικοποιημένη πληροφορία (Gordin *et al.* 1996, Nielson *et al.* 1997).

Κάθε ψηφιακό ερευνητικό μοντέλο πρέπει να συνοδεύεται από τα δεδομένα βάσει των οποίων δημιουργήθηκε. Η καταγραφή των δεδομένων (*metadata*) μιας ψηφιακής αναπαράστασης αποτελεί ζητούμενο ακόμη και σήμερα, σχεδόν 25 χρόνια μετά την πρώτη ψηφιακή αναπαράσταση (εκκλησία του Furness Abbey στη Cumbria της Αγγλίας το 1989) και 23 χρόνια μετά την καθιέρωση του όρου *Virtual Archaeology* από τον Paul Reilly (Reilly 1991, 133). Ενώ όμως υπάρχει το επιστημονικό υπόβαθρο από τις οδηγίες σχετικών Χαρτών, σπάνια καταγράφονται τα μεταδεδομένα μίας ψηφιακής αναπαράστασης (Miller & Richards 1995, 20 και Van Gool *et al.* 2004, Anderson 2003, 21–27, Anderson, 2004, 249–254 για καλά τεκμηριωμένες προσπάθειες). Η έλλειψη καταγραφής των δεδομένων, πάνω στα οποία στηρίζεται μία ψηφιακή αναπαράσταση, δυναμιτίζει τη συμβολή των *Νέων Τεχνολογιών* στο χώρο του πολιτισμού και αποτελεί την κυριότερη αιτία αμφισβήτησης και κριτικής τους ως επιστημονικά εργαλεία από τους «ειδικούς περιεχομένου» (Miller & Richards 1995, 19–22, Earl 2005, 205, Κουρτζέλλης 2009, 11–16).

Η καταγραφή των δεδομένων είναι και ο μοναδικός τρόπος ελέγχου της αξιοπιστίας ενός ψηφιακού μοντέλου. Στη διεθνή βιβλιογραφία υπάρχουν πολλές προσεγγίσεις για τον τρόπο δημιουργίας και διατήρησης των μεταδεδομένων, που κινούνται από την απλή λεκτική καταγραφή έως την προσαρμογή των υφιστάμενων προτύπων για μεταδεδομένα (*Dublin Core*), τις εξειδικευμένες βάσεις δεδομένων που στηρίζονται σε X3D/ XML (Vatanen 2003, 70–72), τις «ψηφιακές βιβλιοθήκες» διατήρησης των δεδομένων, ακόμη και τη σύσταση μιας ειδικής επιτροπής πιστοποίησης ψηφιακών αναπαραστάσεων (Frisher *et al.* 2000, 158) κ.α. Η αναφορά στην αρχαιολογική τεκμηρίωση επιτρέπει στους ειδικούς να διαπιστώσουν για ποια τμήματα ενός αντικειμένου υπάρχει πλήρης, μερική ή ελλιπής πληροφορία. Για την αναπαράσταση του ναού του Μέσσου συντάξαμε μία φόρμα, την οποία ονομάσαμε «Δελτίο τεκμηρίωσης της ψηφιακής αναπαράστασης» (Κουρτζέλλης 2012, 329–332).

Η ιδέα χρήσης ενός μέσου καταγραφής, το οποίο μπορεί να τηρηθεί είτε σε αναλογική είτε σε ψηφιακή μορφή, προέρχεται από μία πιο παραδοσιακή προσέγγιση καταγραφής και τήρησης δεδομένων. Σε κάθε «Δελτίο» καταγράφονται συνοπτικά όλα τα δεδομένα της ψηφιακής αναπαράστασης (διαστάσεις, υλικό, ίχνη χρώματος/κονιάματος, σχέση με το υποκείμενο και υπερκείμενο αρχαιολογικό μέλος, τα «παράλληλα» μνημεία ή αρχιτεκτονικά στοιχεία, οι φωτογραφικές και σχεδιαστικές απεικονίσεις, η βιβλιογραφία) και γενικά όλα τα στοιχεία πάνω στα οποία στηρίζεται η κατασκευή του ψηφιακού μοντέλου και αφορά σε ένα αρχιτεκτονικό μέλος ή στοιχείο. Το «Δελτίο» μπορεί να χρησιμοποιηθεί τόσο από τον ίδιο τον μελετητή-κατασκευαστή των ψηφιακών μοντέλων κατά τη διάρκεια της κατασκευής του μοντέλου ή σε μεταγενέστερη φάση επαλήθευσης ή αξιολόγησής του, όσο και από άλλους μελετητές, οι οποίοι επιθυμούν να ελέγξουν τα δεδομένα της αναπαράστασης. Επίσης, η αναλυτική ψηφιακή σχεδίαση όλων των δεδομένων είναι μια αποκαλυπτική διαδικασία κατανόησης των λεπτομερειών και των ιδιαίτερων στοιχείων που χαρακτηρίζουν ένα μνημείο, καθώς πολλές φορές θεωρούμε ότι γνωρίζουμε όλες τις λεπτομέρειές του, αλλά όταν προσπαθήσουμε να το ανασυνθέσουμε ψηφιακά, διαπιστώνουμε ότι δεν είναι γνωστά πολλά κρίσιμα στοιχεία του, π.χ. ο τρόπος ένωσης του ενός μέλους με το υποκείμενο και το υπερκείμενό του, η γωνιακή διαμόρφωση μελών, οι διακοσμητικές λεπτομέρειες, τα αρχιτεκτονικά στοιχεία που μπορεί να έχουν αποδοθεί σε φθαρτά υλικά όπως το ξύλο (θράνοι, φατνώματα κ.α.) ή ζωγραφικά (Κουρτζέλλης 2012, 332–370).

Η αξία του ψηφιακού μοντέλου για τον μελετητή που οπτικοποιεί τα αρχαιολογικά/αρχιτεκτονικά δεδομένα του είναι μεγάλη, καθώς, κατά τη διαδικασία κατασκευής του μοντέλου, εισέρχεται σε μία σύνθετη διαδικασία αξιολόγησης των δεδομένων και κατανόησης της μορφής του αντικειμένου που αναπαριστά. Σε πολλές περιπτώσεις, το ψηφιακό μοντέλο αποκαλύπτει τα «κενά» της αρχαιολογικής πληροφορίας, κάτι που δεν είναι εφικτό με την αναλογική σχεδίαση, η οποία συνήθως εστιάζεται στην απόδοση της πραγματικής κατάστασης ενός μνημείου. Ένα αναλυτικό ψηφιακό μοντέλο ενός μνημείου έχει επιστημονική αξία, μόνο αν μέσα από τις λεπτομέρειες, που προβάλλονται, μπορεί να βοηθήσει στην κατανόηση και στην επίλυση επιστημονικών προβλημάτων, δηλαδή εάν είναι ανοιχτό σε κριτική θεώρηση. Η συστηματική καταγραφή όλων των δεδομένων μίας ψηφιακής αναπαράστασης (*metadata* and *paradata*) αποτελεί ί και την απάντηση στην αυξημένη κριτική που δέχονται εδώ και χρόνια οι ψηφιακές αναπαραστάσεις μνημείων (Ryan 2001, Frischer & Stinson 2007, 58).

6. Τα αποτελέσματα της ψηφιακής αναπαράστασης του ναού του Μέσσου

Η αξία του ψηφιακού μοντέλου ως ερευνητικό και ερμηνευτικό εργαλείο κατανόησης της αρχιτεκτονικής μορφής του ναού του Μέσσου αναδείχθηκε στην περίπτωσή μας μέσα από την αποκάλυψη μιας σειράς προβλημάτων της αρχιτεκτονικής του ναού, τα οποία δεν ήταν προηγουμένως ορατά και τα οποία είναι ενδεικτικά της διανοητικής διαδικασίας που απαιτείται για τη συμπλήρωση των ελλιπών στοιχείων ενός τόσο σύνθετου κτιρίου, όπως ο υστεροκλασικός ναός της Λέσβου (Εικ. 7).

Εικόνα 7 Τρισδιάστατη απεικόνιση του επιστυλίου του πτερού. Λήψη υπό γωνία, ώστε να είναι ορατή η επιφάνεια έδρασής του (Κουρτζέλλης 2012).

Μερικά από αυτά ήταν: η επισήμανση του προβλήματος της ένωσης των δύο σιμών στις γωνίες του πτερού, καθώς η σίμη των μακρών πλευρών και η σίμη των στενών πλευρών έχουν λαξευτεί με διαφορετική διατομή (Εικ. 8). Η απόδοση των υδρορροών, η μορφή των ακρωτηρίων, η απόδοση των γωνιακών αρχιτεκτονικών μελών, ο τρόπος επίστεψης των εν παραστάσει κιόνων, η στήριξη της στέγης και των οριζόντιων δοκών στα μετακιόνια διαστήματα, η λειτουργία της «υποδοχής» στην πίσω όψη της ζωφόρου (Κουρτζέλλης 2012, 353–357, 366–370).

Εικόνα 8 Τρισδιάστατη φωτορεαλιστική απεικόνιση της ΝΑ γωνίας του ναού. Διακρίνεται η διάρθρωση του θριγκού, τμήμα των ξύλινων φατνωμάτων, αλλά κυρίως το πρόβλημα «ένωσης» της σίμης των μακρών πλευρών και της επαέτιας σίμης (Κουρτζέλλης 2012).

Αρχιτεκτονικά μέλη ιδιαίτερα σημαντικά, όπως το γωνιακό κιονόκρανο, θραύσμα του οποίου εντοπίσθηκε για πρώτη φορά στις ανασκαφές του 2003, αποκαταστάθηκαν ψηφιακά βάσει παραλλήλων παραδειγμάτων, όπως το αντίστοιχο κιονόκρανο της Αθηνάς στην Πριήνη και της Λευκοφρυηνής Αρτέμιδος στη Μαγνησία επί Μαιάνδρῳ. Μηδαμινές ήταν οι πληροφορίες για τα φατνώματα του ναού, τα οποία αποδόθηκαν ως ξύλινα, σύμφωνα με την αντίστοιχη μελέτη του Hoepfner (1990, 1–34) για τα φατνώματα των μεγάλων διαστάσεων ψευδοδίπτερων ιωνικών ναών του 4ου αι. π.Χ. (Εικ. 9).

Εικόνα 9 Τρισδιάστατη αναπαράσταση του γωνιακού κιονοκράνου του πτερού (Κουρτζέλλης 2012).

Παρόλο που η ψηφιακή αναπαράσταση περιορίστηκε στην ακριβή απόδοση της γεωμετρίας του ναού, στο ψηφιακό μοντέλο αποδόθηκαν ενδεικτικά οι χρωματικές εναλλαγές και τα διαφορετικά υλικά δόμησης στην τοιχοποιία του κυρίως ναού, το στυλοβάτη και του θριγκού στο πτερό (Εικ. 10). Οι τοίχοι του σηκού, οι εν παραστάσει κίονες, πλην της βάσης και του κιονοκράνου, η ζωφόρος και το τύμπανο, είχαν κατασκευαστεί από ρόδινο ηφαιστειακό πέτρωμα, το οποίο έρχεται σε αντίθεση με το λευκό πέτρωμα (λιπαρίτη) του υπόλοιπου κτιρίου (Αχειλαρά 2004, 35, Κουρτζέλλης 2012, 368–380 με εικόνες και παραδείγματα).

Εικόνα 10 Τρισδιάστατη απεικόνιση του ναού. Άποψη από τα ανατολικά (Κουρτζέλλης 2012).

Συμπεράσματα

Συμπερασματικά μπορούμε να πούμε ότι η τρισδιάστατη απεικόνιση του ναού του Μέσσου πραγματοποιήθηκε με σεβασμό στις αρχές και τους κανόνες της εικονικής αναπαράστασης αρχαιολογικών δεδομένων. Κύρια μέριμνα υπήρξε η χρήση των τρισδιάστατων γραφικών ως ένα ουσιαστικό εργαλείο ελέγχου και κατανόησης δεδομένων, όπως άλλωστε καταγράφεται στη διεθνή βιβλιογραφία ως το ζητούμενο της «Εικονικής Αρχαιολογίας» (Barceló 2000, 9, Gillings 2000, 59). Επίσης, θεωρούμε ότι βελτίωσε τις σημερινές ακολουθούμενες Πρακτικές στην χάραξη μεθοδολογίας κατασκευής αναλυτικών ψηφιακών μοντέλων, μέσω της προτεινόμενης συνεχούς αξιολόγησης, καταγραφής και ερμηνείας των δεδομένων.

Η ψηφιακή αναπαράσταση του ναού του Μέσσου δεν επικεντρώνεται στην παρουσίαση νέων κατευθύνσεων/τεχνικών (Forte 2008, 21–35), αλλά επιστρέφει στη βασική αρχή της αρχαιολογικής έρευνας – την τεκμηρίωση–, προτείνοντας την αναλυτική σχεδίαση και καταγραφή όλων των δεδομένων της αναπαράστασης, που συνοδεύουν το ψηφιακό μοντέλο, ώστε να είναι διαρκώς διαθέσιμα, τόσο στον ίδιο τον μελετητή, όσο και στους υπόλοιπους ερευνητές, οι οποίοι καλούνται να ελέγξουν την ορθότητα της ερμηνευτικής διαδικασίας που έχει ακολουθηθεί. Το ψηφιακό μοντέλο μπορεί να ανανεώνεται διαρκώς, να συμπληρώνεται και να τροποποιείται, προκειμένου να συμβάλει στην έρευνα ενός μνημείου.

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3D MODELLING AND NAVIGATION TOOLS FOR THE DATA MANAGEMENT SYSTEM OF THE ACROPOLIS RESTORATION SERVICE

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Περίληψη/ Abstract

At the Acropolis Restoration Service a database management system for the documentation of the restoration interventions has been in use through successive upgrades for the past 25 years. Recent activities towards the implementation of 3D visualisation facilities and the simplification of the database structure aim to benefit user-interaction with the database records and achieve improved transaction speeds. A 3D visualisation and modelling tool that has been developed for the segmentation and annotation of 3D textured models of complex architectural features or entire monuments facilitates the association of individual 3D spatial structures with the corresponding database records. This way it is possible to depict the results of queries regarding the state of preservation and the restoration interventions directly on the 3D model of a monument. Combined with data structure improvements, the designed tool enhances data accessibility and visual data examination.

Στην Υπηρεσία Συντήρησης Μνημείων Ακρόπολης ένα σύστημα διαχείρισης βάσης δεδομένων για την τεκμηρίωση των έργων αποκατάστασης βρίσκεται σε χρήση μέσα από διαδοχικές αναβαθμίσεις τα τελευταία 25 χρόνια. Πρόσφατες επεμβάσεις προς την κατεύθυνση της ενσωμάτωσης λειτουργιών τρισδιάστατης (3Δ) απεικόνισης και της απλούστευσης της δομής της βάσης δεδομένων αποσκοπούν στην ενίσχυση της αλληλεπίδρασης των χρηστών με τα δεδομένα και την επίτευξη βελτιωμένων ταχυτήτων απόκρισης του συστήματος. Η ανάπτυξη ενός εργαλείου 3Δ οπτικοποίησης και μοντελοποίησης για την κατάτμηση και την σήμανση 3Δ μοντέλων που αναπαριστούν με υφή πολύπλοκα αρχιτεκτονικά στοιχεία ή ολόκληρα μνημεία, επιτρέπει τη σύνδεση επιμέρους 3Δ γεωμετρικών αντικειμένων με τις αντίστοιχες εγγραφές της βάσης δεδομένων. Με τον τρόπο αυτό μπορεί να οπτικοποιηθεί το αποτέλεσμα ερωτημάτων σχετικά με την κατάσταση της διατήρησης και τις επεμβάσεις αποκατάστασης κατευθείαν επάνω στο 3Δ μοντέλο του μνημείου. Σε συνδυασμό με βελτιώσεις στη δομή δεδομένων, το συγκεκριμένο εργαλείο καθιστά πιο αποτελεσματική την προσβασιμότητα και την οπτική εξέταση των δεδομένων.

Keywords: Laser Scanning, Databases, Monument Documentation, Acropolis, 3D textured Models

Introduction

The Database Management System for the documentation of the restoration interventions of the Acropolis of Athens has been in use since the early 1990's. It was initiated in 1987, when the restoration of the Erechtheion was completed, and since then, it has expanded to cover all restoration interventions. During this time, the system has gone through three major upgrades and many more minor improvement episodes in order to adapt to the growing documentation requirements (Fig. 1).

Data computerisation was initiated in 1987, using the *Sigmini software*, a unix-based information retrieval system which employed a ranked attribute data structure (Mallouchou-Tufano 1993). Through this system around 6000 documents were catalogued concerning the Erechtheion restoration. By the mid-1990s an upgrade into a Windows-based SQL relational database was realised. Its architecture was further expanded across a network to allow multiple users (Mallouchou-Tufano & Alexopoulos 2007). In 2008 another major upgrade was implemented targeting the interface and the addition of data access and query mechanisms. The application code base was migrated from the obsolete Visual Basic 6 to the Microsoft.Net framework and particularly in C# allowing greater flexibility in terms of application functionality and future enhancements.

The architecture of the database has been centred on the archive of the architectural partitioning of the monuments (Alexopoulos 2010). The data structure models the architecture of Ancient Greek articulated buildings through the implementation of a hierarchical partitioning of each monument from the whole (e.g. Parthenon) to each individual building block (e.g. column drum). This archive has been connected to the repositories of the documentation files (photographs, drawings, texts, videos) containing the actual records and their metadata (for example, drawing type, photographer, date of creation). All archives, receive attribute values and data entry restrictions from controlled vocabulary lists that can be further extended by the users.

The hierarchical monument division diagram has been integrated within the system's interface allowing the user to navigate and access the monument part of choice and examine the relevant record. Each record contains information about the identity of the monument part or building block (description and specific position within the whole monument). Available image, text and video data that document restoration intervention events can be selected and their respective records from the relevant archives are displayed. Each record contains basic metadata as well as tools that allow data viewing and manipulation, such as zooming facilities and image contrast and brightness adjusting, text editing and video playing.

The application further contains data querying mechanisms that allow simple and complex query construction. Information from multiple fields can be combined to limit the results. Returned results can be further investigated or exported in a spreadsheet for further processing.

The advantage of this type of data structure allows the management and presentation of individual architectural members or larger sections of each monument together with their entire documentation held in the database, including digital copies of the original documentation files. In this respect, the database comprises an information repository for future generations much as a powerful tool for monitoring and supporting the works, useful for both engineers and conservators.

On account of the intensification of digital data documentation processes in the last decade, database content volume has grown at a geometric rate currently containing approximately 132,000 records. The photographic archive constitutes by far the largest part of the database, including more than 110,000 records. Next follows the drawings archive (11,000), while in the process of the restoration works new entries are still created in the archive of architectural members (10,900).

In the previous software upgrade, a prototype map interface was designed to facilitate data access for the Erechtheion. The 3D model of the Erectheion was used to facilitate the selection of a desired view of the monument, which subsequently returned the drawn section of the selected view on a 2D GIS background showing the codes of the architectural parts as labels. By clicking on a specific architectural piece the pertinent entry was returned. Simple measurements could also be performed within this environment (Fig. 1). This implementation was made possible through the extension of the database schema to include *c.* 30 geographical tables that handled the linkage between the spatial data from each section and the records in the application.

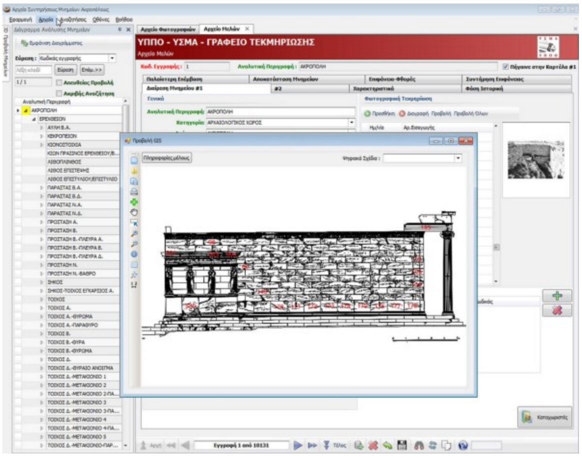

Figure 1 Data access using a 2D GIS interface of the previous version of the Documentation System

Overall, this implementation made minimal use of the Erechtheion 3D model, complicated the database structure, presented performance problems over network and didn't take advantage of the capacities presented in a GIS, since the visualisation remained on a two-dimensional level. As a consequence, the results of complex queries covering the entire monument could not be displayed simultaneously, while the selection of individual architectural parts meant that the user would previously select the appropriate monument side.

Adaptation to the growing documentation requirements meant that, apart from system maintenance and upgrade, further ways to visually convey information and enhance user-interaction with the database records were necessary. In this respect, in the context of the National Strategic Reference Framework (NSRF) 2007-2013, an upgrade project was launched. Alongside the use of updated frameworks and design patterns (i.e. .Net Framework (4.5), Entity Framework 6, Repository and Unity of Work) to enhance system performance, especially with respect to query and CRUD (create/update/delete) mechanisms (see Greenfield & Short 2003), activities towards the implementation of a working 3D visualisation environment and the simplification of the database structure were taken.

The scope of implementation of the 3D visualisation environment aimed to provide the users with a platform in which they could examine 3D models of complex architectural features or an entire monument, identify areas or individual architectural blocks and be directed to the corresponding database records. The possibility to visualise complex queries using the 3D model would enhance data understanding, identify areas with similar characteristics, reveal new associations and locate potential documentation mistakes.

1. Laser scanning products

Among different 3D modelling techniques, laser scanning tends to become a standard procedure in documenting highly demanding and complex objects. The use of laser scanners allows the capture of millions of points per second with high accuracy, while certain scans sessions can reach up to several billion of points (Wand *et al.* 2007).

Within the context of the project for the 'Development of Geographical Information Systems for the Acropolis of Athens' funded by the Operational Programme 'Information Society', which initiated the geometric documentation of the Acropolis monuments, the entire Erechteion building was scanned at a resolution of 5mm for both exterior and interior areas of the monument or even higher (less than 1 mm in areas with sculptured decoration and greater archaeological interest, i.e. the Caryatids), resulting in a textured triangulated surface model made up of 350 million polygons (Grammatikopoulos 2010).

Its availability apart from a documentation product in each own right, presented us with the opportunity to explore data re-use in the extension of the database application. However, the integration of such a model within the visualisation environment requires advanced 3D modelling tools that enable the efficient segmentation and annotation of complex geometrical features.

Work in this line of research is growing over the last decade resulting to different methodologies that are gradually being implemented in various software tools. In the field of digital cultural heritage a number of studies gave particular emphasis to the segmentation and semantic classification of 3D models (Manferdini *et al.* 2008, Manferdini & Remondino 2011). A major issue is related to automated or semi-automated procedures for segmenting a model. Although a number of algorithms and editing methodologies have been developed (Shamir 2008) the geometric complexity of detailed and dense meshes, of the type usually produced within cultural heritage, generally requires manual intervention (Manferdini & Remondino 2010, 116).

At present, a number of open source (e.g. MeshLab, Blender) and commercial software packages offer procedures for the manipulation of point clouds, triangulation, vector editing, texturing and annotation. In order to be used in conjunction with a database they require considerable customisations outside of the programmatic scope of the frameworks in use, creating a limited and unreliable solution in relation to business logic, interface, user experience.

In our case, the necessity to create direct links between segmented model parts and the hierarchical data structure outlined above required the development of a customised 3D editing and viewing environment within the existing DBMS application.

2. 3D visualisation and editing tool

The adopted solution is based on the incorporation of *Eyeshot devDept 3D CAD* components within the application's .NET framework, further complemented with custom routines to fit the needs for editing and annotating 3D model segments in order to associate them with the database records. The implementation is based on a 64-bit architecture for efficient rendering and manipulation of large size 3D models. To guarantee interoperability and minimise potential complexity at an operational level, supported 3D models are based on open geometry definition file formats, such as .OBJ (McHenry & Bajcsy 2008).

The application allows the incorporation of entire models or different individual subsets to overcome rendering problems stemming from very large volume files. After the insertion of a model or a subset into the platform, the user can proceed to its division into meaningful segments that follow the architectural division of a monument and associate those segments with their corresponding data records. On-screen selection of a monument part results in the marking of the corresponding set of the underlying vertexes, which can be further extended or limited to include the entire desirable area (Fig. 2). The selection vertices are being translated to a custom programmatic class and then transformed into a binary serialised object, which can later be retrieved and displayed on top of the textured model. These objects can also be associated with the corresponding database records (Fig. 3). This approach was considered necessary due to the fact that most 3D file formats do not have a layer oriented structure.

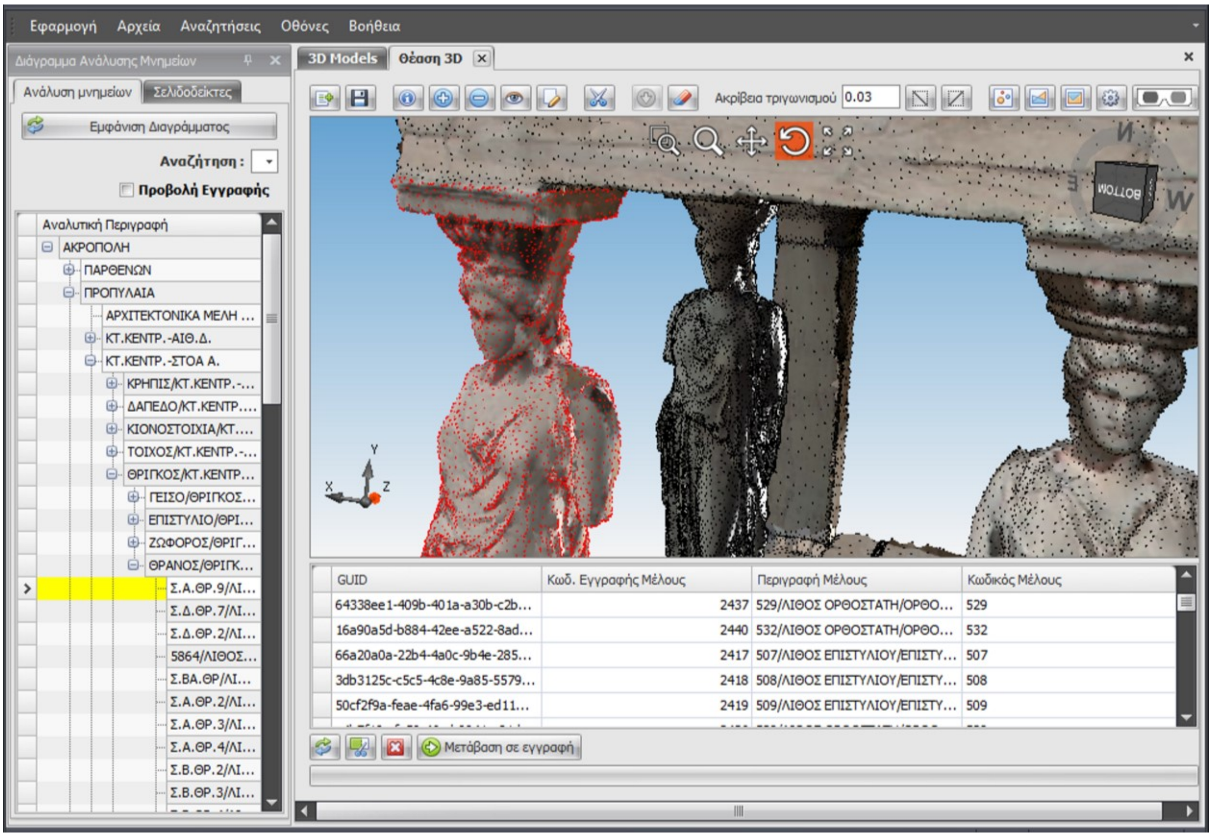

Figure 2 Selecting the area of an architectural feature (Caryatid) from the polygon mesh.

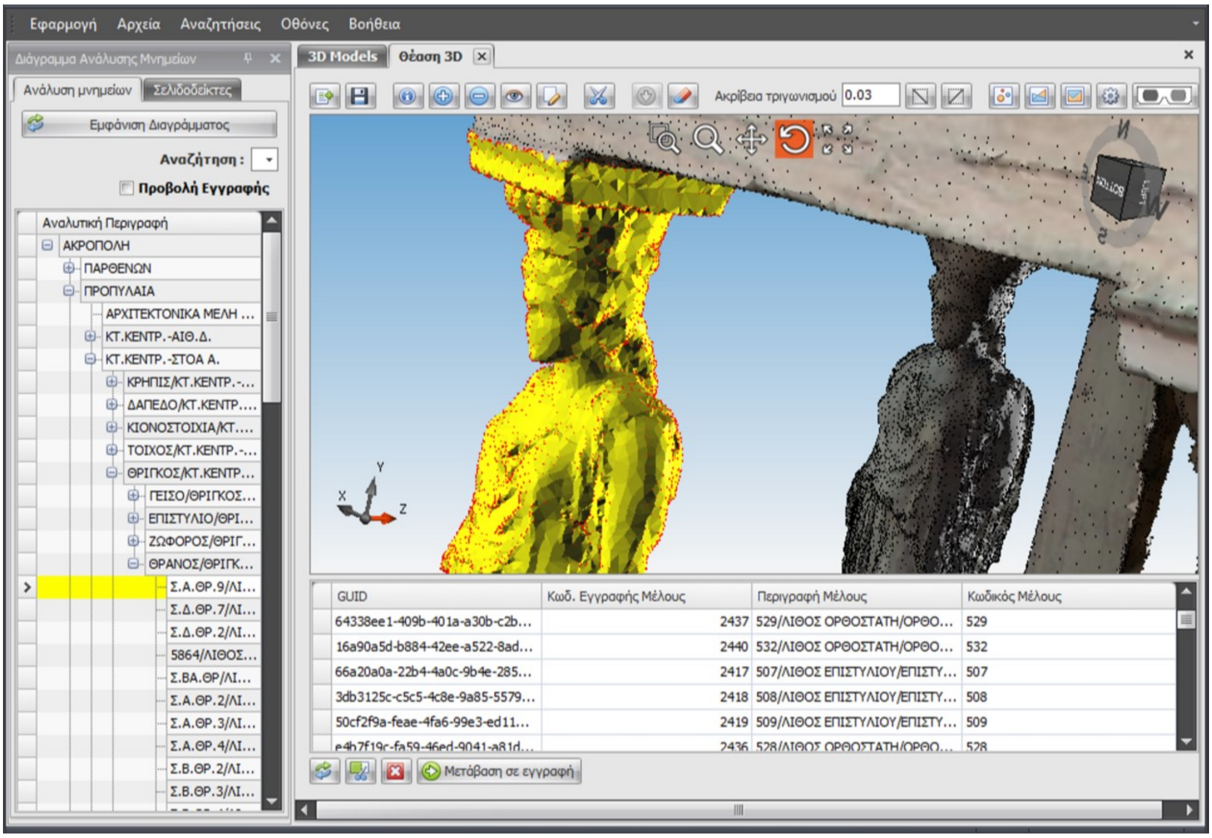

Figure 3 View of the binary serialised object created.

The platform used does not support multi-resolution data (LOD), which could be an efficient way to tackle performance issues over network delivery of the models. Although the developed application workflow is 3D model resolution agnostic, computer hardware limitations urged for a simplified model of the entire Erectheion counting 5 million polygons. This model was annotated and is capable of running seamlessly in any computer with minimum RAM requirement 8GB.

Storage and management of all geometrical objects (textured base models and marked-up segments) are handled by the file system rather than by the database, through their deposition in a shared file repository. In order to overcome potential network speed limitations, the models should be locally present at the client as well; therefore, a simple file transfer mechanism was developed, allowing users to sync the entire repository, or copy individual models on demand.

3. Application Workflow

The user launches the 3D visualisation environment and selects one of the following tasks or workflows:

- Importing a new mesh model;
- Creating a mesh model from a point cloud;
- Viewing and manipulating meshes from objects not related with a particular monument
- Selecting, annotating parts of an existing model of a monument and associating it with database records;
- Viewing and examining annotated segments in combination with their respective data records.

The application supports all the above workflows through different modules for editing, relating and viewing a 3D model. An entire 3D model of a monument or a selected subset can be visualised in three modes; as a textured polygon mesh, as a triangular mesh, or as a 2D rendering.

The editing module includes tools for importing a point cloud, performing its triangulation, facilitating simplification processes, such as smoothing or triangle reduction and adding texture through the projection of images onto selected group of triangles. A model can be deleted or re-imported into the 3D editor for further adjustments.

The associating module allows the user to select and deselect areas of interest, extract them from the full model, enter attribute data and export them to the database as individual serialised binary files. This procedure can be repeated to the remaining structure until the whole model is broken into meaningful entities, associated to the corresponding records and appropriately attributed (Fig. 4).

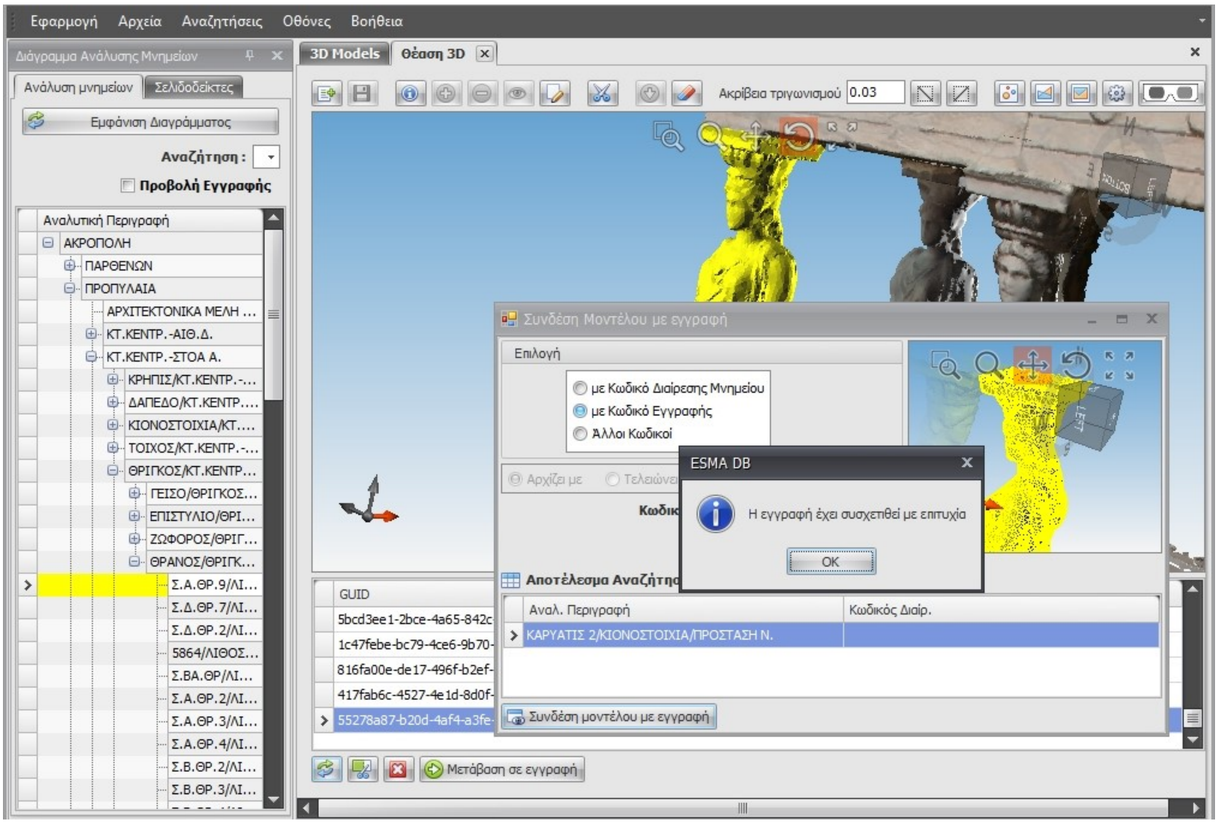

Figure 4 Associating mesh segment with database record.

Finally, the viewing module supports the examination of the entire model or smaller aggregates that correspond to the hierarchical monument division of each monument. Navigation tools can be used to rotate the model, zoom into specific areas, select individual architectural members, and be directed to the corresponding database record that contains all related documentation items on an adjunct tab. Alternatively, the available results of simple or complex queries regarding the preservation state and the restoration interventions can be visualised and colour-highlighted on the model (e.g. depict all restored architectural members containing titanium joints) (Fig. 5).

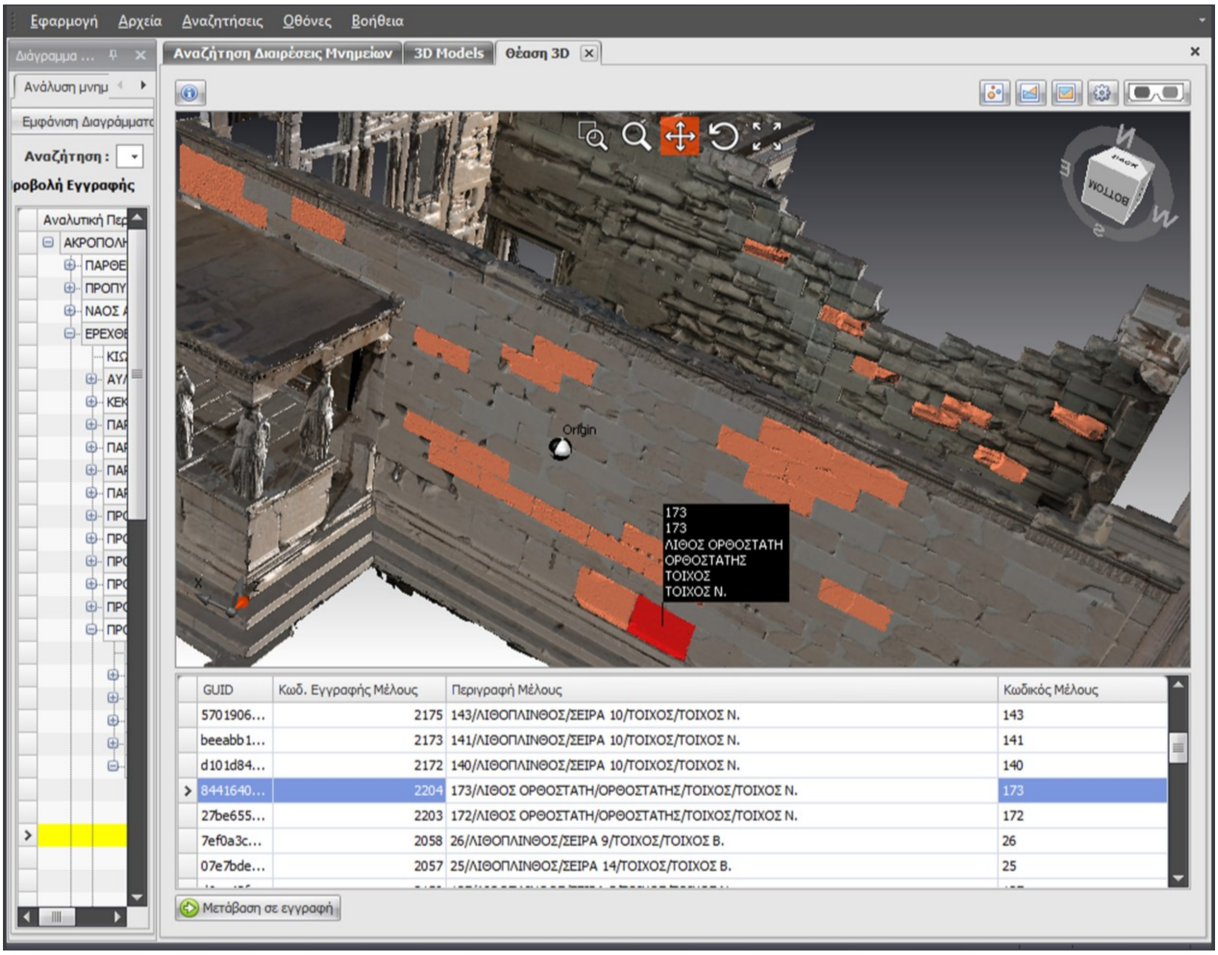

Figure 5 Selection of architectural members containing oxidised joints on the 3D model the Erectheion. The selected record from the result list is highlighted and labeled.

4. Data structure improvements

The implementation of the 3D model viewer and editor led also to the replacement of the spatial tables, supporting the previous 2D GIS solution, with application specific processes that govern the association and retrieval of the 3D geometry. As a result, the data schema was greatly reduced and simplified.

To further enhance the functionality of the visualisation environment and existing data accessing mechanisms, further modifications at the database level have allowed the simplification of the relational structure. More specifically, different document types (images, drawings, text and video) were integrated into a subtyped entity, whose attributes are managed using look up tables. This solution greatly enhanced the original database structure, which required the addition of numerous tables and relations to the database schema for every new artefact type (Fig. 6).

It has also allowed the standardisation of documentation data, since the fields contained in parent table of this inheritance schema are compatible with Dublin Core metadata schema. This way next to the photographic, textual and drawing documentation, video footage and CAD files were added, expanding the set of records that the database manages for each architectural division. These documents inherit the same basic features allowing their simultaneous retrieval in query composition.

Such denormalised configuration simplified development resulting to faster query operations and enhanced user experience (Sanders & Shin 2001). The resulting implementation benefits not only the database performance, but also the link between the 3D texture models and the document types. This is especially true when using the 3D model to depict the results of simple or complex queries (e.g. depict all architectural members containing surface decay record drawings). Finally, it greatly enhances mass reporting and data exporting while it increases the degree of interoperability with third party systems and databases.

Figure 6 Documentation artefact parent table and subtyped tables for each document type.

Conclusions

To conclude, improvements in both the data structure and the user-interface of the database system of the Acropolis Restoration Service have been a key factor to its durability over a period of 25 years. In this last upgrade, the combination of data structure enhancements and 3D visualisation facilities is expected to improve data accessibility and visual data examination.

In this sense, our experience maintains that the long-term efficiency of cultural heritage applications requires constant monitoring and assessment of user needs that are employed in regular incremental updates. This procedure is far better than costly major re-structures, which ran the danger of entangling end-user habits.

This strategy can make use of available data in novel usages providing opportunities for data re-use. Last but not least, a balance should be maintained between extending application functionality and maintaining data simplicity.

The final product will go through a user-evaluation period for detecting potential improvements, which will be used to inform the implementation of the next module extension. This extension targets the incorporation of the Athena Nike temple 3D model, which is the next restoration project that is already concluded and scheduled for survey.

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Cultural Heritage, Archaeological Resource Infrastructures, Management and Risk Assessment

USING WEBGL TO DESIGN AN INTERACTIVE 3D PLATFORM FOR THE MAIN MONUMENTS OF CRETE

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Περίληψη/ Abstract

Η εννοιολογική απεικόνιση της πληροφορίας επιτρέπει τη βελτιωμένη οπτικοποίηση και τον χειρισμό μεγάλου όγκου πληροφοριών. Ιδιαίτερα στην ψηφιοποίηση της πολιτιστικής κληρονομιάς και όταν ο στόχος είναι η παρουσίαση περισσότερων του ενός μνημείων, η αφαίρεση πληροφορίας αποτελεί την διέξοδο. Η προτεινόμενη εφαρμογή έχει ως στόχο να παρουσιάσει τα βασικά αρχαιολογικά μνημεία της Κρήτης και την εξέλιξή τους στον χρόνο, μέσα από ένα εννοιολογικό τρισδιάστατο μοντέλο. Η τεχνική εφαρμογή βασίζεται στη γλώσσα WebGL, επιτρέποντας στον χρήστη να πλοηγηθεί ανάμεσα στα βασικά μνημεία και να τα προσεγγίσει σταδιακά και διαδραστικά, μέσω διαφορετικών επιπέδων λεπτομέρειας. Συγχρόνως, η δυνατότητα μετάβασης μεταξύ επτά ιστορικών περιόδων προσφέρει την συγκριτική μελέτη της εξέλιξης των μνημείων στο χρόνο. Η εννοιολογική απεικόνιση και η αφαίρεση πληροφορίας μέσα από διαφοροποιημένα επίπεδα λεπτομέρειας επιτρέπει στην εφαρμογή να είναι διαθέσιμη σε οποιονδήποτε χρήστη του διαδικτύου, καθώς είναι υπολογιστικά «ελαφριά» και εύκολη στη χρήση.

Conceptualisation of information allows improved visualisation and manipulation of large amounts of data. Especially in digitisation of cultural heritage and when aiming at presenting more than one monuments, abstraction of information becomes the key solution. Our proposed application aims to present the main archaeological monuments of Crete through a conceptual 3D model and their evolution through time. The technical implementation is based on WebGL allowing the user to navigate among the main monuments and approach them gradually and interactively through different levels of detail. Furthermore, the ability to switch between the seven historical periods offers a comparative study of their evolution in time. Conceptualisation and abstraction of information through varied levels of detail allows the application to be available to anyone on the web, being computationally light and easy to use.

Keywords: Cultural heritage; conceptual modelling; visualisation; abstraction; 3D

Introduction

Our goal is to design an online platform open to the public for the promotion of the cultural heritage of Crete, through a simple, user-friendly intuitive environment. Our prime challenge has been how to manage such a large amount of information over the internet, in a transparent, light and simple way for the end user, in addition to offering the ability to compare the monuments' and cultural regions form and structure, during the main historical periods in Crete's history. The idea is simple: instead of presenting information to its full extend available up front, we break it into nodes, levels of abstraction, called 'Levels of Detail', providing the minimum information needed at each given time. Information is stored on each object, each monument, along with its different Levels of Detail consisting of: Crete; Prefecture; Region; Complex; Monument.

Crete is the largest island of Greece, famous for its rich cultural history dating back to the Middle Paleolithic age, 128,000 BCE. Standing out as the most emblematic phase of the island's multi-layered contribution to global and national history, is, undoubtedly the era of the Minoan civilisation (2,700–1,420 BCE). Still, a large number of monuments have been documented throughout the different historical periods, the most important of which are the following seven: Minoan; Classical & Hellenistic; Roman; Byzantine; Venetian; Ottoman; Modern.

Crete being one of the places where most of the cultures which have developed in the Mediterranean have interfered, it is crucial to provide the public with the possibility to produce personal multiple cultural representations and interpretations of the island's polyvalent cultural, historical and geographical scape. It is not intended to promote a strictly architecture-based limited image of Crete's past, but a dynamic understanding of its hybrid cultural identity. In that sense, the points of reference are not strictly based on a 'high culture' agenda; apart from traces of an 'official' historical past, such as the Minoan Palaces and the Byzantine Monasteries of the island, local networks of vernacular settlements and places invested with local myths, legends and events are also to be included. In that sense, addressing history of architecture as part of culture and not just as a catalogue of important buildings *per se*, it is aimed to unfold the ways in which architecture has been developing in Crete as a witness of the inherent cultural dynamics of change and adaptivity as well as tradition and continuity. Sites symbolising the unity of local culture as well as contested places indexing the dialectics of local and regional conflicts form an equal part of our localised references. This is the way to turn all this information into something engaging with the interests of the contemporary cultural traveller.

1. Concept of the Cultural Platform

The targeted users for this application are mainly tourists with a varied degree of general interest in history, architecture and archaeology. This application helps them plan their visits to monuments and provides them with extra information about how these historical sites have evolved through time. It is a helpful and useful tool that can be easily used by a basic internet user.

Most 3D reconstructions of cultural monuments have focused on the photorealistic depiction of these monuments (Ragia *et al.* 2014). The schematic visualisations adopted in this paper, present the monument with only its essential features without descriptive details (Sifniotis *et al.* 2006). In this way, the user is provided with the necessary information in order to perceive a complete picture of the monument.

Herein, the challenge is to present a well structured as well as open in its possible readings array of diagrammatic information operating more as the matrix for direct as well as less straightforward meanings on behalf of the user (Parthenios *et al.* 2012). The sheer concept of the diagram stands at the core of the platform's innovative concept. Knowledge acquisition and interactivity are not necessarily supported and enhanced by an already 'stable' and closed in its interpretation pseudo-realistic rendering. On the contrary, the diagram, in its abstraction as well as open-ended character functions as an initiator of possibilities and potentialities. Added to that, this is indeed the best way to optimise the available storage and processing technologies with the bulk of 3D information so that the cultural platform provided operates effectively on the Internet.

The 3D diagrammatic visualisation depicts the monument without falling short of information, eliminating unnecessary details that can be acknowledged in the near future once the user visits the monument (Gonzalez-Perez & Parcero-Oubina 2011). Therefore, accurate textures for each monument have been avoided and replaced with generic, abstract, textures – which in addition allow for radical shrinkage of the model's total size. After all, the platform does not seek to replace physical reality and the need to engage with it. What is being sought after is no more than an enlarged synergy between the physical and the virtual for the sake of the visitor.

The grouping of monuments is initially based on their geographic location. Each pin represents a monument or a group of monuments that are geographically close. The user, depending on the monument s/he wants to visit, focuses on a region (pin), in which s/he is informed about that monument or about neighbouring monuments for which s/he was not informed. The user may observe the 3D visualisation of the monument in a specific time period, as well as its evolution in time, up to the contemporary period. In this way, s/he is informed about the form of the monument in earlier historical periods as well as about its potential proximity to other important monuments of the same period or other.

At this stage, the monuments that are being presented are the following:

- Kydonia (Chania): Minoan period
- Aptera (Chania): Hellenistic, Roman, Venetian, Ottoman and Modern period
- Yali Camisi (Chania): Ottoman and Modern period
- Venizelos' Residence (Chania): Modern period
- Agora (Chania): Modern period
- Arkadi Monastery (Rethymno): Byzantine, Venetian period
- Etia Villa (Lassithi): Venetian period.

The classification of monuments is based on their geographic location. Crete is divided into four areas (corresponding to the administrative sub-peripheries/ 'prefectures') while and each one is subdivided into a concrete number of municipalities. Each monument is geographically located in a single municipal unit. Each pin represents a monument or a group of monuments that belong to the same municipal unit and are geographically close.

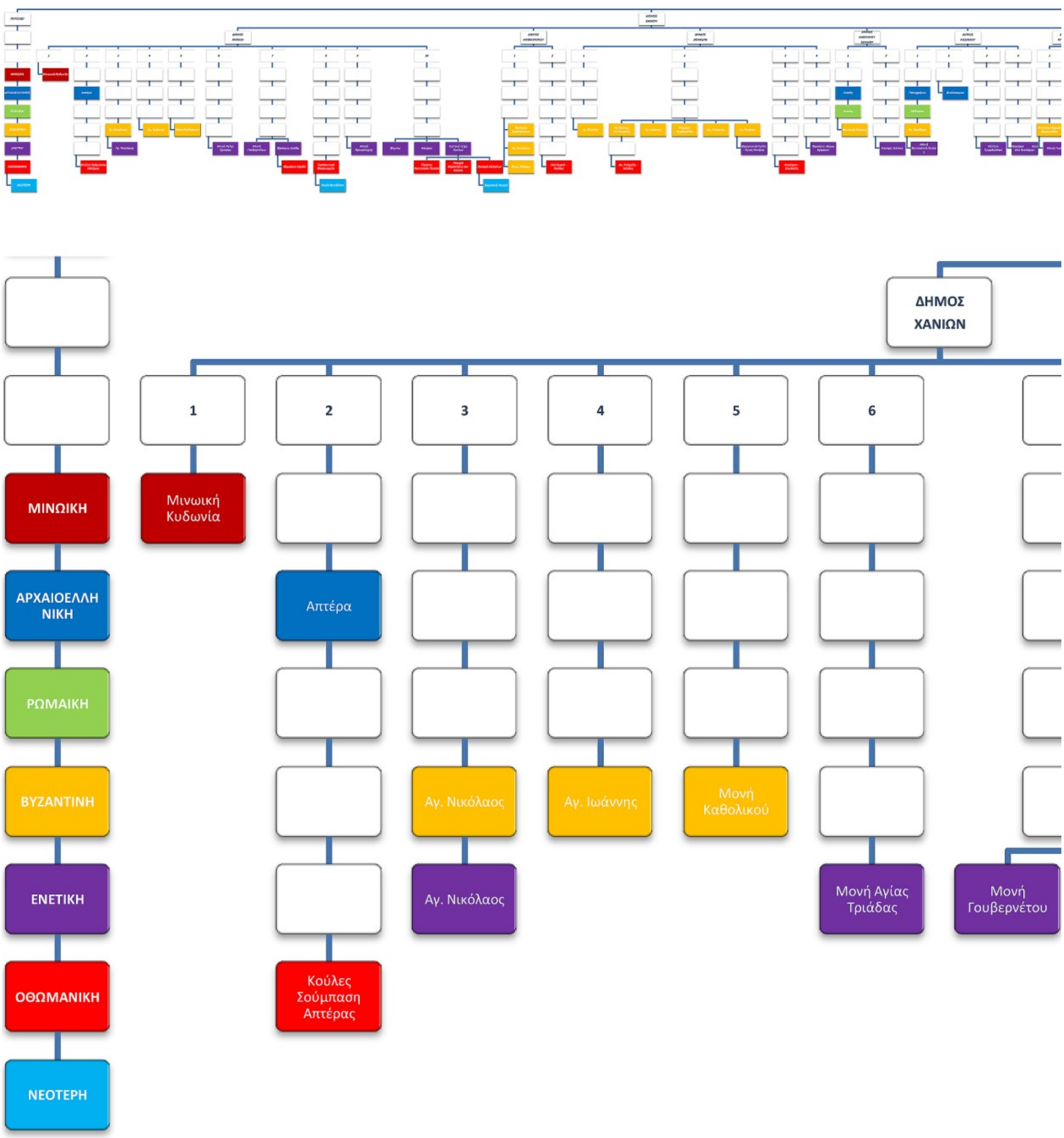

Figure 1 Clustering of monuments (based on location and historical period).

There are five (5) levels of detail as follows:

1. Crete, divided into four prefectures (Fig. 3)

2. The Prefecture: in this level each prefecture is depicted along with the pins of the monuments. The orange colour represents the pins in the time period selected from the horizontal axis of historical periods, while pins in red transparent colour represent monuments from earlier historical periods, which have not suffered any change or addition in the running historical period (Fig. 4).

3. The Region: a part of the municipal unit appears with the monuments of each historical period while the monuments of earlier periods, are depicted with transparency (Fig. 5).

4. The Complex: this level presents the cluster of monuments along with the monuments separately, depending on the historical period that we select from the horizontal (Fig. 6).

5. The Monument in more detail (Fig. 7).

It is essential to also note that, independently from each monument and its specific characteristics, what prevails is a common `language' of representation that runs through the application. In particular, in the level of the Region, the monument that we are each time interested in is presented on a part of the map of the respective municipal unit, along with neighbouring monuments, thus allowing the user to grasp its context both in terms of the other monuments in proximity and of the surrounding urban fabric. The diagrammatic view allows the user to 'supplement' with his own eyes what is visually there based on historical information and the visitor's own interests and past experience.

2. Technology

2.a WebGL

The technology utilised for the implementation of the cultural platform presented in this paper is WebGL. WebGL is a cross-platform, royalty-free web standard for a low-level 3D graphics API based on OpenGL ES 2.0, exposed through the HTML5 Canvas element as Document Object Model interfaces. WebGL is a shader-based API using GLSL (OpenGL Shading Language). GLSL is a high-level shading language based on the syntax of the C programming language employing constructs that are semantically similar to those of the underlying OpenGL ES 2.0 API, adapted for JavaScript. Notably, WebGL brings plugin-free 3D to the web, implemented directed into the browser. Today, WebGL runs in desktop and non-IOS web-browsers such as Mozilla Firefox, Google Chrome, Safari, Opera and the latest version of Internet Explorer. WebGL was selected as the main 3D programming framework for our application mainly because applications are loaded directly to the browser without the need of a plug-in.

Three.js is a cross-browser JavaScript library used to create and display animated 3D computer graphics on a Web browser. Three.js scripts may be used in conjunction with the HTML5 canvas element at a higher-level than WebGL. The advantages of using the Three.js framework instead of native (or raw) WebGL is that the Three.js library has a lot of constructors ready for use and long WebGL code could be replaced by a few lines of code when Three.js is employed. Moreover, the Three.js platform provides model loaders necessary for the display of the 3D models of the monuments.

2.b 3D Models

The 3D models of the monuments are developed in Google Sketchup and exported as Collada files (.dae) as required by the Three.js platform. It is important that the 3D models consist of a small number of polygons as they are being downloaded by users through the Internet in real time. For this reason, the 3D models are modelled in an abstract form without, though, losing the appropriate mesh detail that makes them recognizable and unique. It is also significant that the system is scalable to accommodate a growing number of monuments as well as different parts of Greece or any other country; therefore, intelligent data manipulation so as to reassure easy and fast on-line access is paramount.

2.b Implementation

We have developed an application for 3D interactive presentation of cultural monuments of Crete (Fig. 2-7). The platform implemented in WebGL visualises each cultural monument in five spatial levels of detail representing initially Crete as a whole, then by prefecture, region, complex of monuments and finally focusing on the actual monument. Simultaneously, each level of detail is visualised in seven 7 different time periods. For the first time, the user is able to virtually visit Crete across regions and time. The user interface consists of two bars, one vertical and one horizontal representing the level of detail and the time periods respectively (Fig. 2). The user could click on the desired level of detail and historical period in order to view in 3D the appropriate representation by simple interaction with the mouse. They could also navigate inside the 3D models by performing simple mouse events interactively. The canvas of the application is as large as the browser window. The viewpoint set when each 3D monument or region is initially loaded is specified as the optimal rendering view for the user. The user could zoom-in/out using the scroll wheel of the mouse, or move the position of the camera by drag and drop in order to visualise the 3D model from a different point of view. The 3D models are intended to be clickable adding historical information and further images as the site is being developed.

Appropriate lighting of the 3D scenes significantly enhances the perceived sense of photorealism and presence. After experimenting with various lighting configurations, we set the parameters of the directional lights provided by the Three.js platform, setting their intensity and position in order to achieve the most aesthetically pleasing result.

The shadows are casted by the models as well as the models receiving shadows. In order for shadowing to be implemented, the models are defined as a complex set of surfaces through the code. Therefore, specified surfaces are able to cast shadows and others receive shadows, all belonging to the same model.

In order to keep the web site simple for non-expert users, we use the Three.js's *sprite* which stores in an array the position of the mouse. The position of the mouse as well as the projection of the models on canvas could be combined with an appearing label offering information about each model.

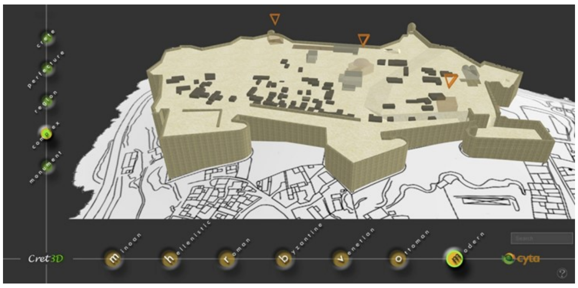

Figure 2 User Interface of the platform, horizontal axis representing historical periods, vertical representing level of detail.

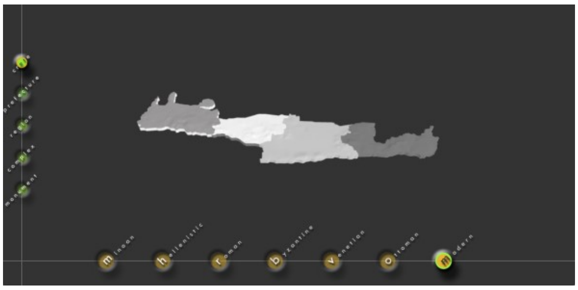

Figure 3 Crete in Modern period.

We setup a database for the models and their associated information using Ajax technologies enabling the asynchronous loading of suitable 3D models without reloading the page. Ajax is a group of interrelated Web development techniques used on the client-side to create asynchronous Web applications.

Figure 4 Prefecture in Byzantine period

Figure 5 Rethymno old town: Region in Ottoman Period.

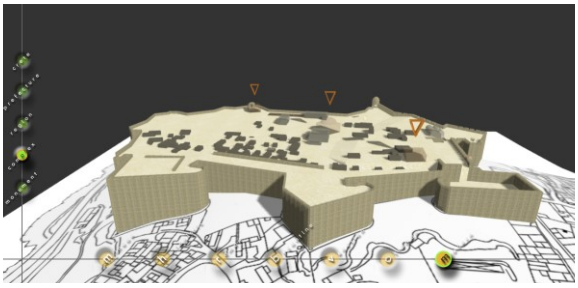

Figure 6 Rethymno old town: Complex in Modern Period.

Figure 7 Rethymno old town: Monument (Pirovolio) in Venetian Period.

Such technologies are necessary because of the sheer size of the 3D models which require optimized loading so that users do not quit the application. Ajax supports the loading of the application without unaccepted latency.

2.d User Interface

The user interface was kept simple and easy to be operated by the user. The most important element of the application is the 3D canvas where the 3D models are being visualised (Fig. 2).

At first we constructed a paper prototype of the interface of our application which helped us to understand the flow between screens and user interactions. A paper prototype enables the visualisation of the user interface based on the successful succession of screens. It showcases which interface elements are more important to put emphasis on and how intuitive it is for our typical user, for instance, a tourist.

The paper prototype was shown to a small set of people, mainly the developers and the researchers in the project. The main web page of the application was designed based on the observations related to the paper prototype so as to avoid elements of the user interface that were not completely understood as well as adding elements that were missing. The user interface consists of two main axes; a horizontal which is the time axis and a vertical which is the spatial axis. The time axis is composed by seven buttons that corresponds to seven main historical periods. The spatial axis consists of five buttons, each one of them corresponding to different spatial levels starting from the most general to the most detailed one.

The design of the buttons is simple and abstract. The colours of the clickable buttons were selected for their contrast with the background which is dark grey. The most important elements of this interface are the two axes, therefore, no other elements were added in order for the design to be clean and simple. For the same reason, we placed the buttons over the 3D canvas that led to a problem. The letters of the buttons in full zoom-in mode while interacting with a 3D model were not readable, so we placed a semi-transparent box behind the letters of the two axes to enhance their readability. At every level of the spatial and time axis a help button is found. By pressing it the user can locate information and a search bar for easy and quick information access.

When the user selects the last level of detail of the spatial axis visualising an interactive monument, a menu is appearing offering certain options. At the right side of the screen a double arrow appears and when the user slides it, a slide menu is available including monument information. The user can select photos, videos, historical and general information associated to each monument etc. The user's choice is being displayed on a pop-up window which is viewed over the 3D canvas and by interacting with the arrows at both sides photos or videos can be viewed. The idea behind user interface decisions was to build an interface that is comfortable to use, also through touch screen devices.

Conclusions

We have developed a web-based interactive platform for the 3D visualisation of cultural monuments in Crete across regions and historical periods. The platform offers a comprehensive view of the wealth of Crete's cultural heritage and its evolution in time. The first phase of the platform will be online and fully functional in November 2014. In the future, the platform may incorporate social media characteristics so as to be more appealing to young people. For example, users could be offered the possibility to leave comments, rate monuments, keep track of monuments visited and also provide recommendations to the users based on their previous ratings.

3D modelling of monuments were mainly based on historical texts, sketches and drawings. Further development of our modelling approach would be to import primary and secondary monument information from different sources. Primary data may include measurements from field observations, mainly survey. Secondary data may consist of information that has already been processed or imported in other datasets. Digital recording in archaeology is widely used and photogrammetry is one major acquisition technique. Data from aerial and close range photogrammetry may also be imported. The idea would be to enrich our prototype with the integration of photogrammetric data, which provide valuable information about the facades and the location of the monuments.

An additional component of the system would be the integration of our prototype with a Geographical Information System (GIS). GIS is a powerful tool for data storage, management, analysis and visualisation and involves mathematical functions for further analysis of archaeological data. GIS information could be combined with location-based services so that in future extensions, the application is aware of the position of the user and automatically loads the relevant information if, for instance, the user is near or at the area of a cultural site.

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DEVELOPMENT OF A CULTURAL HERITAGE MANAGEMENT SYSTEM-IMPLEMENTATION TO THE ANCIENT ATHENIAN AGORA

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Περίληψη/ Abstract
Τα Συστήματα Διαχείρισης Πολιτιστικής Κληρονομιάς περιλαμβάνουν συνήθως τη γεωγραφική αναφορά των αντικειμένων της Βάση Δεδομένων. Η Αρχαία Αγορά της Αθήνας αποτελεί έναν από τους σημαντικότερους Αρχαιολογικούς τόπους στην Ελλάδα. Στη διάρκεια των αιώνων της ιστορίας της κατασκευάστηκαν και καταστράφηκαν πολλά Μνημεία. Συνεπώς, είναι κατανοητό πως αποτελεί έναν περίπλοκο και δυσνόητο Αρχαιολογικό Χώρο, ακόμη και για ειδικούς μελετητές. Σε αυτή την δημοσίευση περιγράφεται και αναλύεται η ανάπτυξη ενός συστήματος διαχείρισης του πολιτιστικού αποθέματος της Αγοράς. Το σύστημα βασίζεται στο λογισμικό ArcGIS, χρησιμοποιεί ως χαρτογραφικό υπόβαθρο την πρόσφατη ορθοφωτογραφία της περιοχής και για το σχεδιασμό του ελήφθησαν υπόψη διάφορες παράμετροι. Για την ανάπτυξη του αντικειμενοστραφούς συστήματος προηγήθηκε ο εννοιολογικός σχεδιασμός της Βάσης Δεδομένων με το Μοντέλο Οντοτήτων-Συσχετίσεων (E-R Model). Το μοντέλο που προέκυψε περιγράφεται και αξιολογείται για την αποτελεσματικότητά του. Με την πειραματική λειτουργία του συστήματος αναδείχθηκαν ορισμένα προβλήματα, τα οποία περιγράφονται και καταδεικνύεται ο τρόπος αντιμετώπισής τους. Τέλος, διατυπώνονται οι μελλοντικές προοπτικές και ενδεχόμενες χρήσεις ενός τέτοιου συστήματος, που μπορεί να είναι εκπαιδευτικές, επιστημονικές αλλά και να καλύπτουν καθημερινές ανάγκες για τη διαχείριση των Πολιτιστικών Αγαθών.

Cultural Heritage Information Management Systems have been developed to include the geographic reference of the items in the database. The Ancient Athenian Agora is one of the most significant archaeological sites in Greece. During the centuries of its life many buildings were constructed and destroyed. Hence it is easily understandable that this vast archaeological site is complicated and difficult to understand even by experts. In this paper the development of a Cultural Heritage system is described and analyzed. The system is based on the ArcGIS software, has as base geographic material a recent orthophoto of the area and for its design several parameters were taken into account. The notional design of the data base with the Entity-Relational (ER) model preceded the development of this object oriented system. This ER model is described and evaluated for its operability. After the initial experimental operation of the system, several practical problems were identified. They are also presented together with the way they were confronted. Finally future prospects are being attempted and eventual uses of such a system are proposed. They range from educational and scientific to even covering every day needs for the Managements of Cultural Heritage objects.

Keywords: Information Management System, Cultural Heritage, Database, Ancient Athenian Agora

Introduction

The risk of degradation or even destruction of the Monuments, due to environmental or human factors, was recognized worldwide in the 19th century and the realization of this danger was the first step towards the protection and management of Cultural Heritage. The rapid progress of technological advances in recent years has affected, among others, the management process of Monuments. The technological know-how combined with advanced hardware and software, have contributed decisively to the production of alternative base material, but also to the development of procedures for the documentation and management of Cultural Heritage. At the same time the contemporary mentality of interdisciplinary approach to this very sensitive sector resulted to the awareness of the potential users of these technologies and their acceptance by an ever increasing number of users.

Management of Cultural Heritage assets, tangible or intangible, is a domain in which the Information and Communication Technologies (ICT) are being extensively implemented.

Hence, the Cultural Heritage Information Management Systems (CHIMS) have been developed. These Systems usually include the geographic reference of the items in the data base, i.e. their exact location using Geographic Information Systems (GIS) technology. Cultural Heritage Information Management Systems are gradually gaining in popularity and use among the specialists responsible for the curation of the cultural heritage assets, i.e. archaeologists, restorers, historians etc. Consequently a number of such systems have been already developed and are implemented sometimes even via the web (Agapiou *et al.* 2008, Foote & Lynch 2011)

1. The Ancient Athenian Agora

The Ancient Athenian Agora is one of the most significant archaeological sites in Greece. It is located northwest of the Athens Acropolis and it was for centuries the center of social, political, cultural, administrative and cultural activities of the city. The site includes some of the most well preserved Monuments of the country, such as the Temple of Hephaistos, the Stoa of Attalos and the church of the Holy Apostles. The changes of the structures and the character of the area over the centuries are of great importance. Many of the buildings were demolished and new ones were constructed, usually on the top of the older ones, often using the remaining materials. It was also common to change the shape, the position or the use of the same building from one historical period to another. All these facts make the Athenian Agora site a difficult but, at the same time, a very interesting case of study.

This paper describes the development of a Cultural Heritage Information Management System that was designed and implemented for the management of the Monuments of the Ancient Athenian Agora. The system has been developed within the framework of the compilation of a Diploma thesis (Hatzithoma 2014).

2. System Requirements

The main idea of the project was the design of a system capable of documenting and highlighting the Monuments of the Archaeological Site of the Ancient Athenian Agora in many ways. The design of the system was developed according to the needs of the 1st Ephorate of Prehistoric and Classical Antiquities, who are in charge of the site. In general, it is a system that enables the visualization of the structure of the Agora over time, through dynamic maps, and at the same time it gathers and organizes temporal data that are related to the monuments.

The essential requirements of the system included an easy to operate computer application, capable of storing and maintaining the necessary data and related information, while at the same time simple to use even by non-experts. As for the technical details, the system should be able to record, store and present different types of data, spatial and non-spatial and also combine those data in multiple ways. Additionally it should organize and present the data to thematic layers, enable the georeferencing of spatial information and it should also support raster base maps for the depiction of the spatial data.

3. Design of the System

In order to fulfill the above requirements a Geographic Information System (GIS), combined with an exterior Database, has been selected for the implementation of the system. GIS have proven to be very useful for Cultural Heritage management. They may contribute from the initial activities of archaeological study to the organization and highlighting of the monuments of an Archaeological Site. What makes the GIS popular in Cultural Heritage applications is the way they manage the objects, based on their spatial attributes, such as position, shape and dimension. Georeferencing of the spatial data can be combined with non-spatial information and stored easily and quickly in a GIS system, so that they can be used at any time in different ways, depending on the application. (Georgopoulos & Ioannidis 2008)

The centralized nature of the developed database system provides several advantages, such as greater data integrity and independence, reduced data redundancy, reduced updating errors and increased consistency, reduced data entry, storage, and retrieval costs. Thus, the improved data access to users, through use of host and query languages, and flexibility of the system are ensured. Therefore it is able to contribute to the geometric recording of any kind of Monuments, from the simplest to the more complex one (Hill *et al.* 2009).

The database design was achieved taking into account many different factors, primarily identifying the exact aim, which will be served by the application. The result should be a tool of knowledge, information and promotion of the Archaeological Site of the Ancient Athenian Agora with a structure capable of storing and combining spatial and descriptive information regarding the Monuments. An important task was to organize the information in a way to point out the temporal changes in the shape and the function of the Agora over the centuries, so that the user can manage and interact with the Monuments and the pertinent information either temporally or locally, i.e. for a particular point of interest in the archaeological site. Moreover, the overall design had to ensure the interaction of the Database with a Geographic Information System and the ability to organize and view the geospatial data across layers. Therefore, close cooperation with the future users, i.e. the archaeologists responsible for the site at the initial stages of the system design, led to detailed identification of every possible question, query and requirement a user may have from the system. In addition, the data managed by the system, their type and the relationships developed among them were determined.

4. Conceptual Modeling

The main objects of the DBMS are the Monuments and the finds of every historical period in the Agora. They were described by their position, size and shape. All other data include information describing the Monuments and are associated with them according to the era they refer to.

For the easier comprehension of the system, the database is divided in two subsystems. The first subsystem includes all the general information for every monument, like date, description, and administrative, historic and architectural information, descriptions of visitors, images, gravures, artistic drawings, digitized photos, digital images, video and three dimensional models (Fig. 1). As for the entities of the second subsystem, they have been selected and related in such a way to represent the basic steps of the geometric documentation of a Monument (Fig. 2). The connection of these two parts is realized with the "*Geometric Documentation*" relationship and through the connection of the concepts and procedures of geometric documentation with its final products, like drawings and three dimensional models.

After their definition the entities and their attributes were properly related. At the end, 23 entities and 28 interrelationships were defined. The representation of the conceptual model was made with the following Entity Relationship Model (E-R Model, Fig. 1).

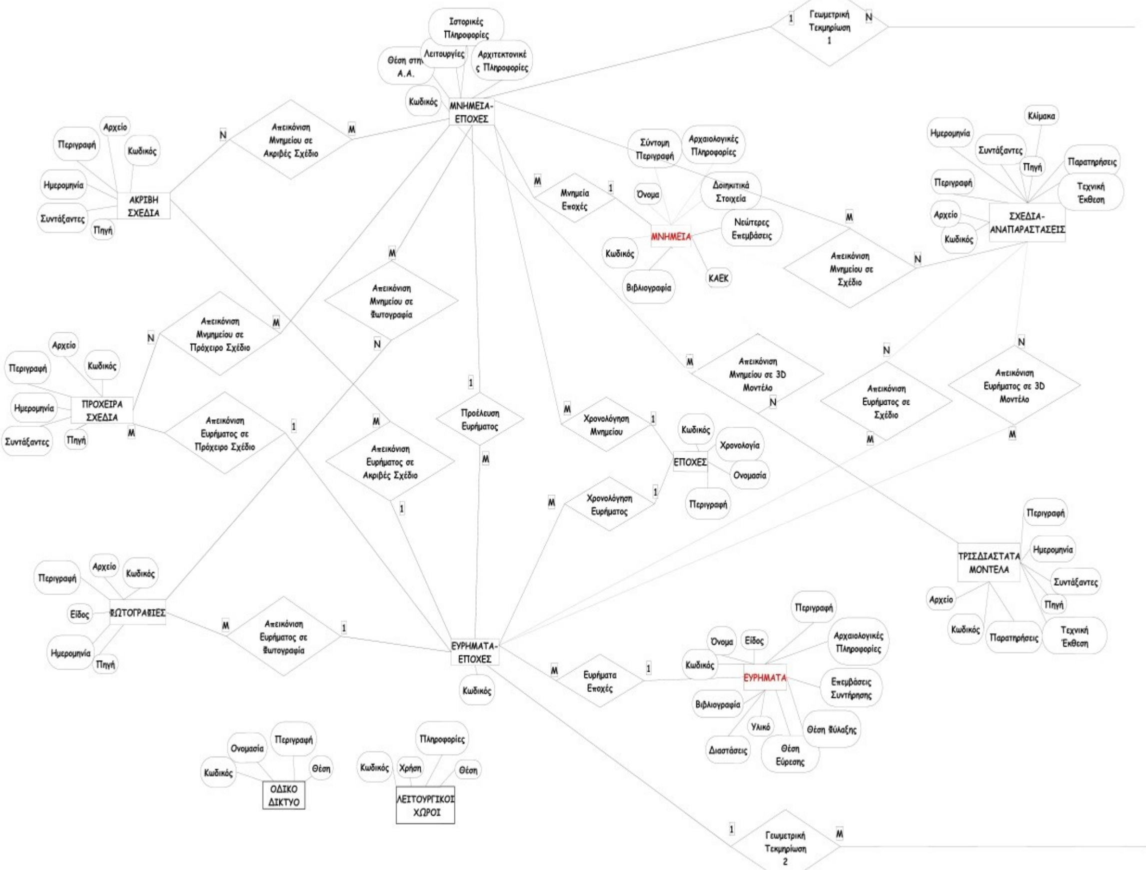

Figure 1 The E-R Model of the first subset (Hatzithoma 2014).

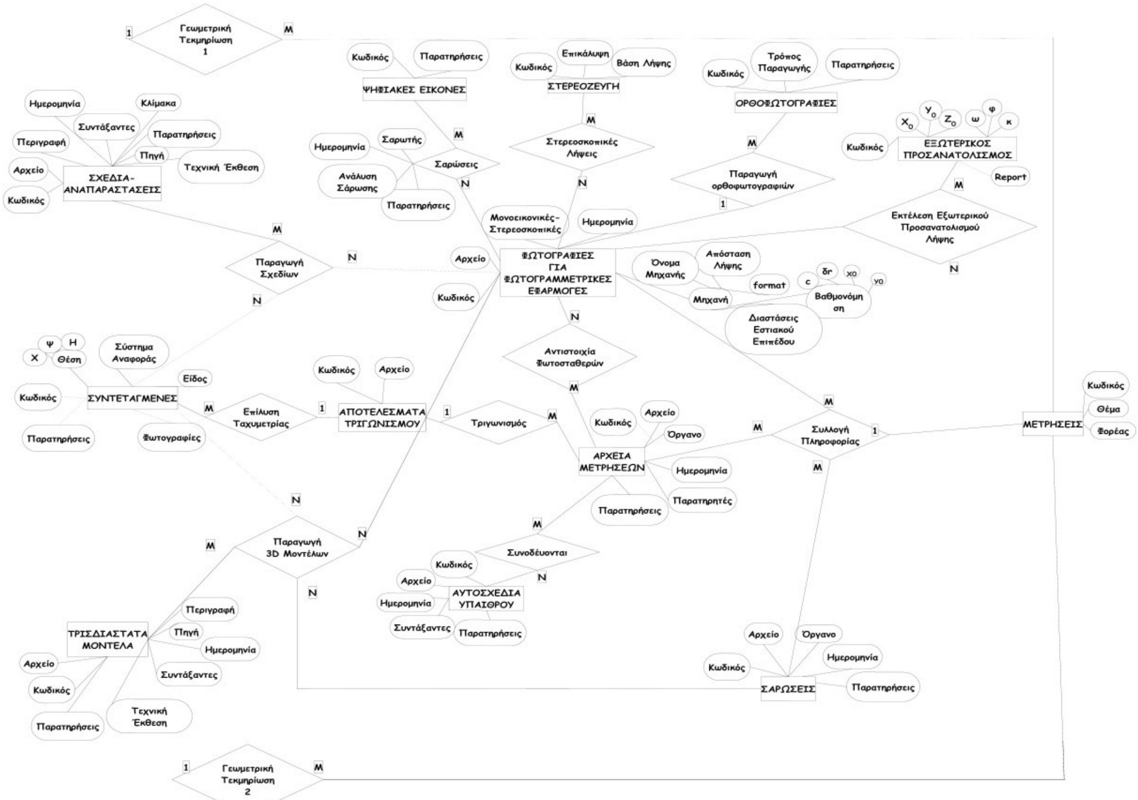

Figure 2 The E-R Model of the second subset (Hatzithoma 2014).

5. System Implementation

The system consists of two basic parts that were implemented according to the design of the database and are interacting: a Geographic Information System (GIS) that includes the non-spatial data designed on georeferenced base-maps and an exterior database that organizes the descriptive information.

The GIS project was created using the ESRI ArcGIS® software. The system includes seven raster base maps, georeferenced to the Greek National Reference System, each of which represents the Athenian Agora in a specific historical period.

Figure 3 The orthophotography of the Athenian Agora in 2007 (Ktimatologio 2007).

On these base-maps the footprints of the monuments that existed and could be projected in each era were drawn, along with other spatial data, like the main entrances of the site, facilities like infrastructure for disabled persons, washrooms and shops, the surrounding road network and pathways of moving around in the site (Figs. 3–5). The spatial data describing each era are organized in a different layer, so by projecting one layer on the other and with the appropriate background changes the evolution of the Agora during the centuries becomes obvious. There are also map tips, displaying the name of each monument as well as hyperlinks to short descriptions, when hovering with the mouse over a feature of interest. (Johnson & Wilson 2003).

The system includes seven georeferenced base maps, an orthoimage of the area of 2007 provided by Ktimatologio S.A. and six plans from the guide *The Athenian Agora Site Guide* (Mck Camp II 2010). In ArcGIS the Monuments are spatial data with unique position, shape and size, which change from one era to another. The main idea was to depict all the Monuments that existed or exist to date in the Agora and at the same time show in which age each one was created and if and how it has evolved over the time. The representation of the Monuments was achieved by their design as polygons, lines or points on the base maps. For each different era image the Monuments have been designed and can be projected in different layers.

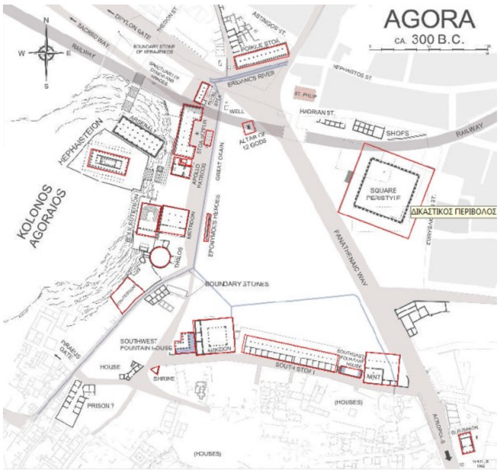

Figure 4 The state of the Agora in 300 BCE. (Mck Camp II 2010).

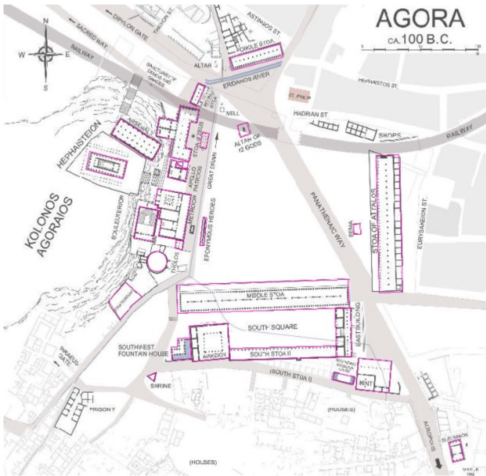

Figure 5 The state of the Agora in 100 BCE. (Mck Camp II 2010).

All other pieces of information were organized and stored in a geodatabase, in tabular form along with their attributes and metadata. For the easier update and management of the database, suitable forms were created for each table (Fig. 6). These forms contain some action buttons for the most common commands of the database.

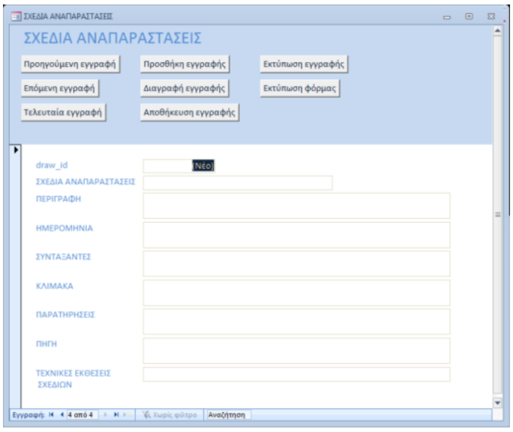

Figure 6 Blank form of the table for drawings (Hatzithoma 2014).

The spatial data design of the system in ArcGIS, was followed by the construction of the Database that includes the descriptive information for the Monuments. The tool was selected for this purpose was a geographic database that was created in ArcGIS and was expanded and fully developed in MS Access environment. The type of the Database is a Personal Geodatabase, where all the data are stored in MS Access tables and are available to many users. It is a model that supports and combines spatial and non-spatial data stored in tables, in an object oriented environment, where the entities are represented as objects with properties while maintaining the integrity of their geographic characteristics. In the .mdb file of the geodatabase all the data considering the spatial objects designed in ArcMap application were imported. New tables were also added, containing data for the descriptive entities of the Database. Each entity of the ER Model is a unique table in MS Access, with the same name. The tables were related according to the initial notional design. The geodatabase that was formed is a supportive tool of the GIS for spatial design, but it can also be used separately. The ArcGIS application and the Microsoft Access database interact and are properly connected, but they may be used separately, according to the user's needs.

A Java Application was also created for the easier presentation of the data stored in the database. The application is executed using Mozilla Firefox. The application is based on SQL queries that were carefully formulated in order to select and export the descriptive information of the database along with their relationships, in XML files. These files were used in a Java script code, which is executed using Mozilla Firefox and contributes to a simple, organized presentation of the data (Figs. 7 and 8). The Access Database includes a variety of information for the Monuments of the Ancient Athenian Agora that is stored in tabular form. For their presentation the Java application was created. The first step was the formation of queries in MS Access and the export of the results of their execution to XML files. The queries were built using SQL language. They were formed in order to select the appropriate files from the Database, along with some of their descriptive information and at the same time to maintain the relationships between them and with the polygons of ArcGIS. The Java script was structured based on these XML files.

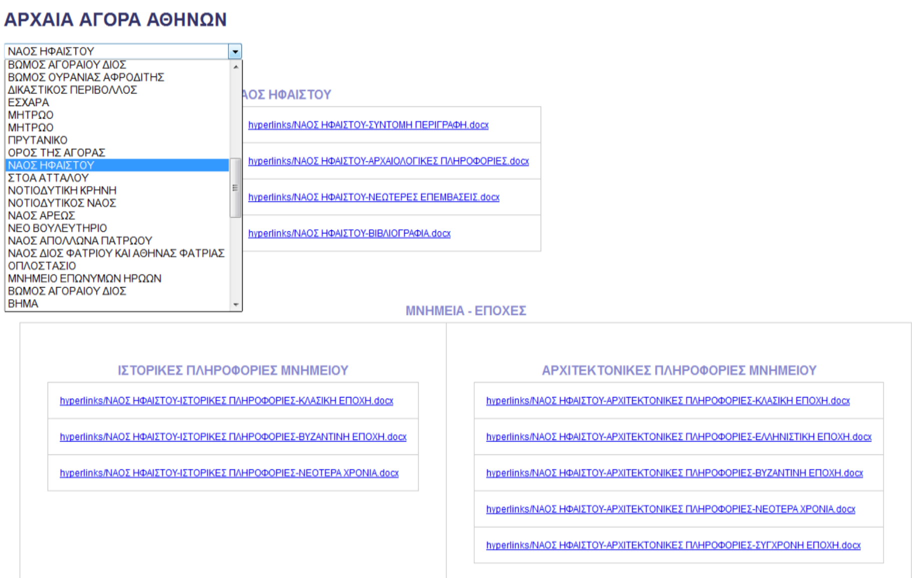

Figure 7 Screenshots of the presentation of the information for the Temple of Hephaistos (Hatzithoma 2014).

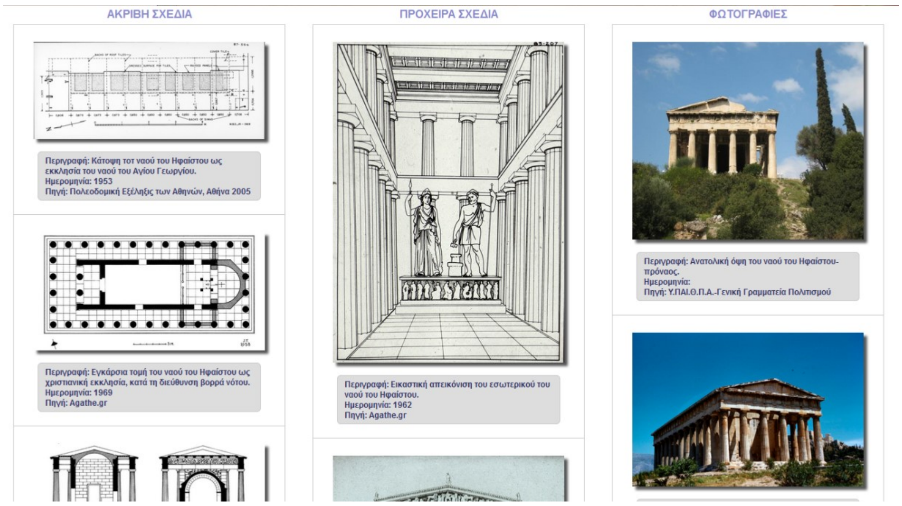

Figure 8 Screenshots of the presentation of the information for the Temple of Hephaistos (Hatzithoma 2014).

Conclusions

The *Cultural Heritage Management System-Implementation to the Ancient Athenian Agora* is an attempt for collecting and combining data for the Monuments of the site in a DBMS managed by a GIS. The main goal is for this system to evolve to a useful tool of organization and retrieval of different types of data. So far the system contains information only for three of the monuments of the Agora, but in the future it should be completed and updated. The information stored in the database may be used by a non-specialist and provide general information. At the same time, the metric data that are organized in the second subsystem can be used in specialized applications. The system is managed by various authorized users. With slight changes it can be easily adapted and expanded for many applications, like educational purposes, information of the visitors of the site or more specialized applications, by architects or engineers.

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INTEGRATING ENVIRONMENTAL AND ARCHAEOLOGICAL DATA FOR RESEARCH AND ARCHAEOLOGICAL HERITAGE MANAGEMENT PURPOSES. A GIS-BASED GEO-ARCHAEOLOGICAL ARCHIVE FOR URBAN CONTEXTS WITH COMPLEX STRATIFICATION

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Περίληψη/ Abstract

Οι ανθρώπινες δράσεις εγγράφονται στο τοπίο. Διαφορετικά είδη δραστηριοτήτων λαμβάνουν χώρα σε μία περιοχή στη διάρκεια του χρόνου, με διαφορετικά επίπεδα σχέσης και με μία σε μικρότερο ή μεγαλύτερο βαθμό ισχυρή σύνδεση με τα περιβαλλοντικά χαρακτηριστικά του τοπίου. Αυτή η αμφίδρομη σχέση πρέπει να εξεταστεί μέσω μιας κριτικής καταγραφής και παρουσίασης της αρχαιολογικής μαρτυρίας και των περιβαλλοντικών χαρακτηριστικών στο πλαίσιο μιας στρωματογραφίας. Στην ανακοίνωση παρουσιάζονται θεωρητικές και μεθοδολογικές αρχές για τη δημιουργία μιας ολοκληρωμένης ανάλυσης που ενσωματώνει διαφορετικά στοιχεία και αποσκοπεί σε μία δυναμική αναπαράσταση των ανθρωπογενών και φυσικών στοιχείων του τοπίου και της διατήρησής τους. Ως παράδειγμα παρουσιάζεται ένα ψηφιακό αρχείο χωρικών δεδομένων που στοχεύει στην καταγραφή, διαχείριση και ανάλυση γεωαρχαιολογικών δεδομένων, ενσωματωμένο σε ένα σύστημα Γεωγραφικών Συστημάτων Πληροφοριών (GIS) με εφαρμογή στην πόλη της Ρώμης.

Human activities occur in the landscape. Different kinds of activities can take place in a single place over time with varying levels of association and in lesser or greater correlation with the environmental features in that landscape. This interrelation needs to be examined through a consistent and critical recording and mapping of archaeological evidence and environmental records, stratigraphically interpreted. In this paper, theoretical and methodological guidelines will be outlined for the performing of integrated analyses aiming at a dynamic reconstruction of the human and natural history of landscapes and their preservation. A digital spatial archive dedicated to the recording, management and analysis of geo-archaeological data integrated with a GIS system that was implemented for the city of Rome will be presented as an example.

Keywords: Man-environment interaction, geoarchaeology, GIS, cityscape.

Introduction

Different kinds of human activities can occur in a single place over time with varying levels of association and in lesser or greater correlation with the environmental features in that landscape.

In order to determine and evaluate the diverse activity areas detected in a portion of the landscape, it is crucial to consider both the presence and absence of remains and traces of human activities there. In order to do so, the creation of an integrated and interdisciplinary digital environment is needed, with a two-fold goal: as a research tool, for a dynamic and long-term reconstruction of ancient landscapes; and as an administrative tool, for archaeological and landscape heritage management. Such an environment, GIS-based, would constitute a dedicated tool which aims at the management of archaeological landscape data that is useful for both scientific and administrative purposes.

In attempting to detect, interpret and analyse human choices in the past history of a territory, we can define activity areas, which are often named '*task-areas*' or '*activity-areas*' in literature and are both linked to environmental and cultural factors (production area, habitation/dwelling area, market area, etc.) (Kuna 1991, Venclova 1995).

By analysing each piece of evidence, or unit of archaeological evidence, in terms of environmental context and cultural/historical landscape, we can proceed to a progressive logico-spatial process of the known evidence, at different levels. A GIS system, with its analytical and relational logic, helps define these 'objects' through the graphical representation of polygons (or groups of polygons) associated to a specific function and a specific information content. Those polygons are created by 'deconstructing' the available archaeological record, through a 'source critique' operation, or rather a metadata attribution. This should be done in terms of an evaluation of the quality of the information, as well as of data management, for instance with a determination of typology or the indication of the modality of discovery. The record is consequently reconstructed in terms of units of social activity, extracting the meaning of each individual component in order to better evaluate the large and often incoherent (i.e., acquired in various manners and different times) quantity and variety of available archaeological data (Van Leusen 2002, Farinetti 2011a), (Fig.1).

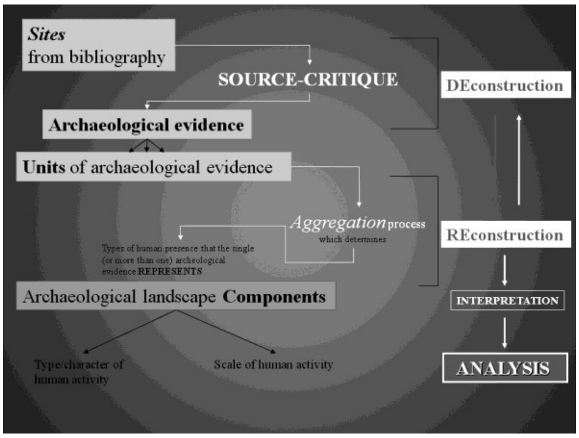

Figure 1 Model of deconstruction and reassessment of the archaeological record (Farinetti 2011a).

In this paper, I will focus on the first part of the diagram, which concerns the meaningful pre-processing and GIS recording of the archaeological data sets, since the reconstruction and interpretation of data constitutes a further step that requires more precise historical questions and which, in my opinion, needs to be applied differently in distinct geographical areas and contexts.

1. Methodology

As seen earlier, the work is theoretically based on the assumption that landscape is a dynamic interaction of anthropogenic and environmental factors continuously changing over time, a constantly morphing product of nature meeting culture (Tilley 1994, Gosden 1999, Ingold 2000). In this respect, the absence of archaeological remains in a location is not to be considered emptiness, but rather a presence of different landscape features, often a product of environmental processes, strictly linked, related and spaced out with the moments and processes of human history. As mentioned, this assumption can be considered valid both for research and for the protection and management of archaeological heritage, especially in an urban and suburban context with complex stratification and a high density of invasive research. As for the latter, the absence of archaeological/cultural evidence cannot be seen simply as an information gap, but rather a presence of environmental features and processes that bias or affect the visibility of archaeological record or possibly even explain its absence. This kind of information, if correctly registered, would allow for a consistent picture to be reconstructed, perhaps the most complete picture possible, of the archaeological potential of a specific area. Furthermore, it would enable archaeological services to intervene at diverse levels, with the ultimate goal of protecting and safeguarding archaeological heritage (Fig.2).

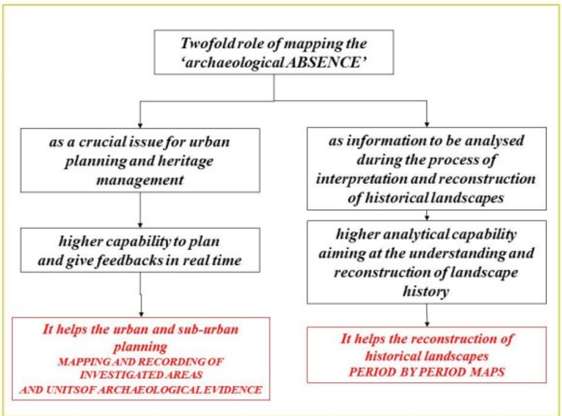

Figure 2 The twofold role of the 'absence' of archaeological record.

In this framework, focus should be given to the complex and dynamic interaction between natural and anthropogenic processes. By analysing the various aspects and moments of that interaction (who/what influences whom/what; who informs what/whom; how the interaction takes place), the potential meaning of the archaeological evidence (or groups of archaeological features) can be inferred. The degree of representativeness can consequently be determined with the help of a critical evaluation of the available archaeological record, in terms of people's past choices in the landscape that the evidence represents.

For instance, if we were to focus on the area of Rome, an example can be offered by the abandonment of buildings or entire areas due to various flooding events of the Tiber river, whose deposits, when not cleaned up, formed a layer of natural origin stratigraphically rooted in the human history of that particular area. A further example could be the *tufo* plateaus, which mark the countryside around Rome. They were originally created by the eroding action of the Quaternary streams on volcanic soils and were modelled in the long term by agricultural activities. The modern landscape is now characterised by cultivated naked plateaus and steep slopes left (on purpose!) with wild vegetation in order to avoid further erosion (Fig.3).

Moreover, by paying attention to the co-presence of signs of natural processes that were spaced out with human actions, we can better understand how many 'natural' features were influenced by human activities. For instance, we could refer to the reconstruction and mapping of the final course of the Almone stream, a tributary of the Tiber River that was canalised in Roman Imperial times in order to constitute a natural ditch running along the Aurelian wall. One can also mention the geo-archaeological investigations carried out on the final course of the Tiber River, which crosses Rome, that clearly demonstrate at what extent anthropogenic activities along the river banks conditioned the natural meander-ness of the river in its final course (Marcelli *et al*. 2009), (Fig.4).

From these few examples one can infer the variety of possible interactions that can be reconstructed and analysed in a GIS environment, where both urban dynamics of city contexts with complex stratification as well as countryside dynamics can be meaningfully managed.

Figure 3 Tiber River flooding area in correspondence to the city of Rome and quaternary streams (C. Rosa). The latter are shown in the picture (bottom right).

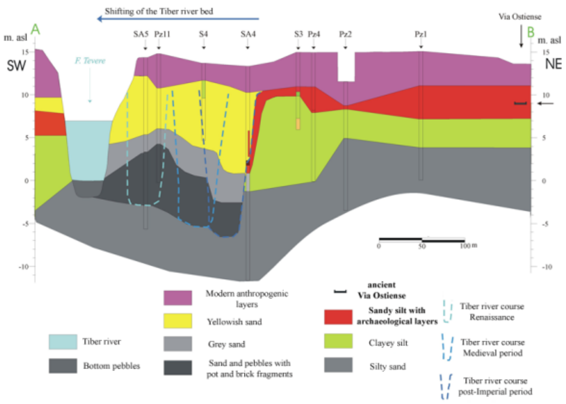

Figure 4 Reconstruction, on the basis of geo-archaeological and geo-gnostic data, of the shifting of the Tiber River in the urban area of Rome. (Matteucci, Rosa, Sebastiani, SSBAR 2002, published in Marcelli *et al*. 2009).

As said, in addition to the attention given to the archaeological evidence recorded and mapped in the system, one should also focus on the absence of archaeological record in certain spots and on the consequent presence of natural features. In order to better analyse the interactions, the main issue becomes the determination of both the depth of the archaeological deposit (top and bottom depth value for each unit of archaeological evidence, expressed in meters a.s.l.) and its 'absence', as well as of the general depth reached by the investigation. Multiple depth values are important to determine the chronology and to detect the different levels of ancient occupation (especially in complex pluri-stratified urban contexts), as well as for heritage protection and urban planning, as seen earlier.

Accordingly, non-anthropogenic deposits should be also recorded and mapped as well as modern or contemporary strata, paying attention to their depth, thus allowing for a quick fruition of data coming from previous soundings on the same spot. Consequently, the dedicated system should include information related to the general character of the 'layers' detected by archaeological and geo-gnostic investigation, and specifically the information coming from core samplings and profile readings, meaning the anthropogenic or natural character of the deposits, the presence of bedrock or of more recent deposits, or the combination of more than one on the same spot (Fig.5).

Figure 5 Traces of ancient activities beneath the modern city. Rome, Ricci Curbastro street: signs of an ancient quarry and carved *tufo* blocks.

Products of the investigation within a research and heritage management framework of this kind can, for instance, be: a precise mapping of the presence or absence of archaeological evidence in the locations where investigations have been carried out, with the precise indication of the reached depth and spatial extension; a careful mapping of the environmental data recorded by archaeological and non-archaeological investigations, once again with the indication of depth values and spatial location; the modelling of reconstructed paleo-surfaces and the long-term behaviour of hydrological features (rivers and streams, marshy areas).

2. The example of Rome

For the city of Rome, for instance, where underground stratigraphy is marked by a high degree of complexity, the creation of a system of this kind has proven to constitute a real and urgent need. It took the form of a digital relational archive, namely a geo-archaeological spatial database, and it is being implemented in cooperation with the geo-archaeological laboratory of the archaeological service of Rome (R. Matteucci, C. Rosa). The system is GIS-based, and it is strictly linked with the wider GIS of the area, a WEB-based product named SITAR that was created especially to serve the management and protection of the archaeological heritage of the larger area of Rome (in the hands of the Archaeological Service of Rome: Serlorenzi 2011). The wider GIS system was implemented using the sql language, written in Ruby for Grails, based on PostgreSQL, and offers an Access interface as well as a Web-based user-friendly interface, created using Symfony open-source software. Map data are supported by *MapFish* technology, linked for the time being to an Autodesk *Map Guide* Server (De Tommasi *et al*. 2011).

Following the general logic of the SITAR system, the geo-archaeological archive is based on an investigation-discovery logic, taking for granted the issue that theoretically every archaeological find is linked to an investigation or a research carried out in a certain time-span in a certain place, which is included in the administrative record of the archaeological service. Thus, every investigation produces one or more finds, either anthropogenic or environmental.

The series of information gathered from each investigation, mandatory for administrative purposes, is also useful in measuring the quality of the archaeological and environmental finds retrieved, in particular by indicating the discovery type which allowed for the archaeological (and/or environmental) knowledge, as well as the circumstances of the discovery. Therefore, information on the investigation constitutes a first level of qualifying metadata on the archaeological and environmental information.

Within the system, both the investigations and the archaeological and environmental macro-finds / units of archaeological evidence have a logical distinctiveness (at the attribute level) and a spatial distinctiveness (position and graphic representation), managed by the alphanumeric archive and by the graphical layers respectively, within the system. At the initial stage, finds are recorded as macro-features, according to large distinctions: typological, chronological and functional. The macro-finds level includes both archaeological finds and layers, as well as material and layers deriving from natural processes, base rock, alluvial deposits or recent human deposits (Farinetti 2011b).

The geo-database which strictly records geo-archaeological data is still a work in progress (Fig.6). The system architecture is based on the individual soundings; the retrieved layers are considered as units of archaeological evidence and are logically linked to the macro-finds / units of archaeological evidence of the wider GIS of the area. Therefore, within the macro-finds archive, the results coming from geo-gnostic investigations and open profile readings are also mapped and registered. Those investigations offer in many cases the main source of information for the natural processes interrelated to human history. Each layer of the drilling core corresponds to a unit of archaeological evidence, with its spatial and attribute component. This allows for a quick mapping of the archaeological and environmental evidence and consequently for a detailed knowledge of the absence of archaeological deposits at certain depths, something which is useful for heritage protection and urban planning.

The system can delve into deeper levels of detail, recording stratigraphical excavation units and detailed results from core samplings. It will record and map all data concerning geo-gnostic soundings (from core drillings, open readings, geo-archaeological data from excavations) in the entire wider area of Rome. The recorded information is much more detailed compared to the archive previously illustrated and linked to the wider GIS of the area. In the case of core drillings, for instance, it includes: typology, executor, person in charge of the reading, place of conservation, multiple depth values of each detected layer, general and detailed chronological attribution with reference to the dating elements, layer components and layer interpretation.
The database is implemented in SQL language and the access to the archive is temporarily allowed through a series of Microsoft Access forms, specifically designed for data updating and retrieval. In the graphical archive, core samplings soundings are represented as 2D polygons and 3D cylinders, with a specified top depth and bottom depth and a known diameter. Consequently, the same representation is employed for the layers detected within each individual sounding.

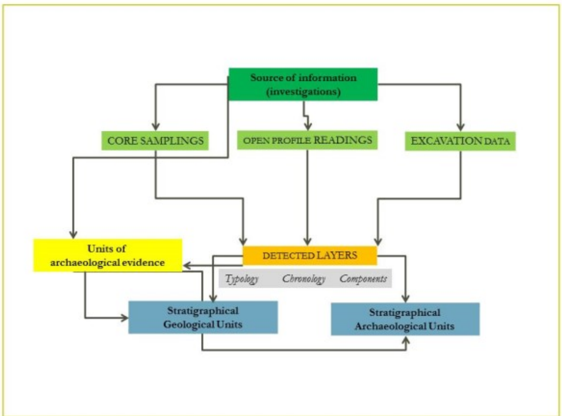

Figure 6 GEO-archive Data Model.

Conclusion

In conclusion, I would like to stress that the paper aimed at setting up a logical framework within which any archaeological GIS should be moving, aiming at the management of the known archaeological record and at the investigation of the interaction between environmental and human data in urban contexts with complex stratification. Thus, my considerations did not refer directly to a specific software application, but rather constitute a theoretical framework and a logical structure applicable and implementable in different systems.

As seen above, such a logical architecture for the system has been positively employed in two related contexts within the archaeological service of Rome, in a wider sense in the GIS system of the Archaeological Service of the city (SITAR GIS system) and in particular to the so-called geo-archaeological archive of the Archaeological Service, where the logic based on a dynamic man-environment interaction is being carefully and fruitfully applied.

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ENDANGERED CRETAN LANDSCAPES: USING DIGITAL APPLICATIONS AND GEOSPATIAL INFORMATION FOR THE RECORDING AND MONITORING OF RECENT LANDSCAPE TRANSFORMATION IN SOUTHEAST CRETE

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Περίληψη/ Abstract

Η περιοχή γύρω από την πόλη της Ιεράπετρας στην νότια ακτή της Κρήτης αναπτύχθηκε ραγδαία τις προηγούμενες δεκαετίες ως αποτέλεσμα της εντατικής χρήσης θερμοκηπιακών καλλιεργειών στην παράκτια ζώνη μεταξύ της Ιεράπετρας και του οικισμού Μύρτου στα δυτικά. Παρ' όλη την ανάπτυξη του βιοτικού επιπέδου στην περιοχή, η εντατική ισοπέδωση λόφων και πλαγιών για την εγκατάσταση νέων θερμοκηπιακών μονάδων έχει αλλοιώσει ανεπανόρθωτα το τοπίο με δραματικά αποτελέσματα για τα ιστορικά και αρχαιολογικά μνημεία της περιοχής. Η συγκεκριμένη μελέτη αποσκοπεί σε πρώτο στάδιο στην καταγραφή των θερμοκηπιακών μονάδων στην πεδιάδα της Ιεράπετρας από τα τέλη της δεκαετίας του 1960 μέχρι σήμερα με την χρήση αεροφωτογραφιών και σύγχρονων GIS εφαρμογών. Ο σκοπός της μελέτης είναι η δημιουργία ενός πλαισίου για την καλύτερη εκτίμηση επιβλαβών παραγόντων (χωματουργικά εργασίες, περιοχές υπό κάλυψη, κ.α.) που μπορούν να επηρεάσουν το πολιτισμικό τοπίο στο άμεσο μέλλον και την διαφύλαξη συγκεκριμένων περιοχών που έχουν αποφύγει μέχρι τώρα τις καταστροφικές συνέπειες των θερμοκηπιακών καλλιεργειών.

Modern agricultural practices (greenhouse plantations) and more recently, solar panels, have covered the majority of the large coastal valley around the modern town of Ierapetra on Crete. Even though the plastic greenhouses contributed to the development of the small coastal town and its surrounding settlements into one of the wealthiest areas on Crete, the physical and cultural landscape of the region suffered immensely. The goal of this project is to document and assess the extent of landscape transformation in the area and provide suggestions for the protection of threatened cultural sites in the southern part of the Ierapetra Isthmus.

Keywords: landscape change, landscape management, greenhouse agriculture, landscape archaeology, site recording, cultural heritage, aerial photography, landscape vulnerability assessment, digital applications

Introduction

The following paper examines how aerial/satellite imagery, in combination with geospatial data, are being employed in the coastal plain of Ierapetra, East Crete, in order to document recent landscape modification and to better understand land use patterns in the region. Moreover, the study addresses recent concerns regarding the consistent destruction of archaeological sites in the area to be replaced by vast greenhouse plantations in the coastal valley and the surrounding bulldozed hills (similar concerns had been expressed by Grove and Rackham (1993) with respect to landscape changes in west Crete). The project was inspired by current trends regarding human-landscape interactions in the Mediterranean regions (Dodouras *et al.* 2009, Naveh 2009, Vogiatzakis *et al.* 2008, Dudley & Stolton 2007, Meyer 2006, Mazzoleni *et al.* 2004, Pachaki 2003).

The project took place on the eastern part of the island of Crete in Greece. An archaeological study of the settlement history of the southern part of the Ierapetra Isthmus in East Crete was undertaken by one of the authors from 2006–2008 (Chalikias 2013). The main motivation for this project was the general lack of knowledge regarding the existence of ancient settlements in the valley around Ierapetra in contrast to the southern part of the Mirabello Bay, an area which had been extensively studied during the past 30 years, contributing to our better understanding of the socio-political developments that had shaped this part of the island since the Bronze Age. After two seasons of archaeological and topographical survey in the area, it became clear that the dramatic transformation of the physical landscape had made it extremely difficult to document and map archaeological sites since most of the coastal valley was covered by greenhouse plantations. This troubling picture led to this project in an attempt to understand how recent land use patterns in the region had changed the cultural landscape of the southern Ierapetra Isthmus and how we could propose ways to protect future sites from possible destruction.

1. Ierapetra and the greenhouse industry

The plain of Ierapetra is a long coastal strip measuring approximately 50 km² (Fig. 1). Prior to 1960, the land around the town was used mainly for barley and wheat cultivation, and secondly for olive oil production, and small-scale seasonal vegetable plantations. The situation changed with the arrival of the Dutch agriculture expert Paul Kuypers in 1966 (Papadopoulou-Kontopodi 2003, 35–37). He saw the agricultural potential of the area, mainly due to the ideal weather conditions; temperatures in the town of Ierapetra vary throughout the year ranging in average between 10˚C and 22˚C in the wintertime and between 22˚C and 35˚C in the summertime. Such favorable conditions allowed for the production of vegetables during the mild Cretan winter months in plastic greenhouses, a farming technique introduced by Kuypers that was unknown to most Cretans at the time. Greenhouses in the Ierapetra region were built by using a metal or wooden frame and plastic (nylon) walls. Today, Ierapetra is known for the dense cultivation of large coastal areas with greenhouses for the production of seasonal vegetables (tomatoes, cucumbers, peppers, and eggplants) and flowers (Mathioudaki-Dragasaki 2009). The construction of a water dam at Bramiana in the early 1980's, ca. 5 km from the town of Ierapetra, increased the water supply for the irrigation of the agricultural fields and produced a surplus of agricultural products that were exported to the Greek mainland and countries in central Europe.

Even though the greenhouse sector contributed to the economic rise of the small coastal town of Ierapetra during the past 40 years, its negative impact was enormous on the cultural and environmental heritage of the region.

Early on, most of the greenhouses were built on the fertile valley around Gra-Lygia, Myrtos, and Ierapetra. Sand dunes from the close-by coastal areas were completely removed as sand was used for the leveling of uneven surfaces in the construction of greenhouses. When most of the flat coastal areas were occupied with greenhouses, farmers expanded their agricultural activities to the nearby hills and mountains. Hill slopes and mountain tops were completely leveled without any environmental planning, changing the geomorphology of the area and its physical and cultural landscape (see Sánchez-Picón *et al.* 2011, Wolosin 2008 for the effects of greenhouse agriculture in the coastal region of Almeria, Spain; Gellynck *et al.* 2005 discuss the need for zoning regulations regarding greenhouses adjacent to urban areas). In some instances and in order to increase the square footage of a new greenhouse, thousands of cubic meters were dug out of the mountain, marking the landscape with a huge visible scar. Such actions can be devastating for the local communities since they increase the risk of damage caused by erosion, landslides, and floods.

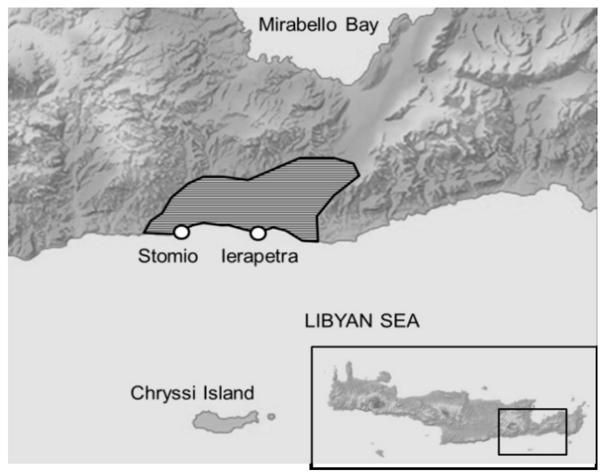

Figure 1 Map of the Ierapetra Isthmus with outlined area of study.

A discouraging fact for the preservation of the physical and cultural heritage of the region is that today, an area of approximately 10 km² around Ierapetra, Kentri, Stomio, and Gra-Lygia has been covered by greenhouses and solar panels to a smaller extent (Mathioudaki-Dragasaki 2009, 99–102, Demos Ierapetras 2008, 35–38). In addition to greenhouse agriculture, the region has recently become a haven for "green" energy companies who install hundreds of solar panels in the coastal valley of Ierapetra and nearby hills without any consideration to landscape preservation. Solar power stations (or solar farms) are usually set up on hill tops, hill slopes, and more rugged mountainous terrain since most of the flat, fertile land around Ierapetra has been taken by greenhouses. Even though in a smaller scale, solar farms follow the recent trend of bulldozing and leveling slopes and changing the geomorphology of the area in order to accommodate hundreds of solar panels that require a flat ground for fixed mounting.

Further, solar farms, due to the high-voltage power infrastructure have restricted access and are usually inaccessible to archaeologists and cultural preservationists. Solar farms and wind farms (concentration of wind turbines) which at the moment are absent from the Ierapetra area are included in a number of renewable energy projects across Crete proposed by the government-controlled Regulatory Authority for Energy (RAE). Even though the concept sounds appealing, several local environmental groups have raised concerns regarding the exploitation of Crete’s natural resources and unique untouched landscapes within the next couple of years (Παγκρήτιο Δίκτυο Αγώνα 2012).

Figure 2 The coastal area of Stomio in 1960 (photo courtesy of Greek Military Geographical Service) and the same area covered in greenhouses in 2010 (Source: Google Earth).

2. Methodology, data collection and preliminary results

The primary goal for this project is mapping the extent of human activity in the region of Ierapetra with the use of historical aerial photography and satellite imagery and document how modern agriculture has dramatically changed the natural and cultural landscape of the coastal valley (for similar studies see De Aranzabal *et al.* 2008, Sarris *et al.* 2005, Papanastasis *et al.* 2004). Further, the objective is to create a database that will allow scientists and policy makers to detect areas of environmental and cultural significance and place them into categories/zones based on their proximity to “high risk” areas that have suffered most by human intervention. The project will allow us to extract useful data that will help in vulnerability assessment of endangered cultural sites in the area and propose solutions for their future protection.

Several aerial images available at the Greek Military Geographical Service and covering the southern Ierapetra Isthmus in the 1960’s at variable altitudes proved valuable for our understanding of land use and settlement distribution in the area before the advent of greenhouse agriculture. Particularly relevant appeared to be some frames from late September 1960 (taken by the USAF) that show the area of Nea Anatoli (Stomio) with several plots of land left uncultivated and void of greenhouses (Fig. 2). Additionally, preliminary observations indicate a coastline transgression of about 80 m in certain parts along the Nea Anatoli (Stomio) shore. Comparing these aerial photos to modern satellite imagery demonstrated the dramatic landscape transformation that occurred in the area before Kuypers’ agricultural innovation.

Further, preliminary results revealed a large number of archaeological sites that were in grave danger due to their close proximity to greenhouses, industrial, or residential areas. Even though the sites were visited several times between 2006 and 2012, it was a number of recent satellite images that helped us evaluate the situation and understand the degree of vulnerability that these sites were facing. In addition, the detailed study of aerial images revealed several areas that were potentially of high interest and accessible for archaeological field survey a few years ago but have been completely covered with greenhouses and solar panels ever since.

The only documented instance of a destroyed archaeological site in the Ierapetra area was recorded in 1992 when a bulldozer damaged two Late Minoan III chamber tombs during the construction of a greenhouse ca. 1 km northwest of the village of Gra-Lygia (Fig. 3). According to Apostolakou, a survey for further tombs and the associated settlement was impossible since all areas around the archaeological site had been already covered by greenhouses (Apostolakou 1998, 25). Five examples of threatened archaeological sites will be discussed in this article in order to demonstrate how urgent it is to take action for the immediate protection of the cultural landscape of the region. Vainia Stavromenos and Anatoli Schistra are within our study area while Paplinou, Myrtos Pyrgos, and Myrtos Phournou Koriphi are in close proximity to our region. Vainia Stavromenos, a multi-period site, spanning from the Final Neolithic to the Late Minoan III period is located on and around a rocky outcrop immediately east of the village of Vainia, *c.* 4 km northeast of Ierapetra. The site, identified by K. Nowicki, has been already damaged due to the construction of a dirt road that bisects the settlement along the western slope of Stavromenos (Nowicki 2002, 29–31). The landscape around the site has been used for decades for the cultivation of olives and as a grazing ground, however, recent satellite images show that from 2002-2010, 12 new greenhouses were built southwest

Figure 3 Satellite image of the southern Ierapetra Isthmus with sites mentioned in the text (Source: Google Earth

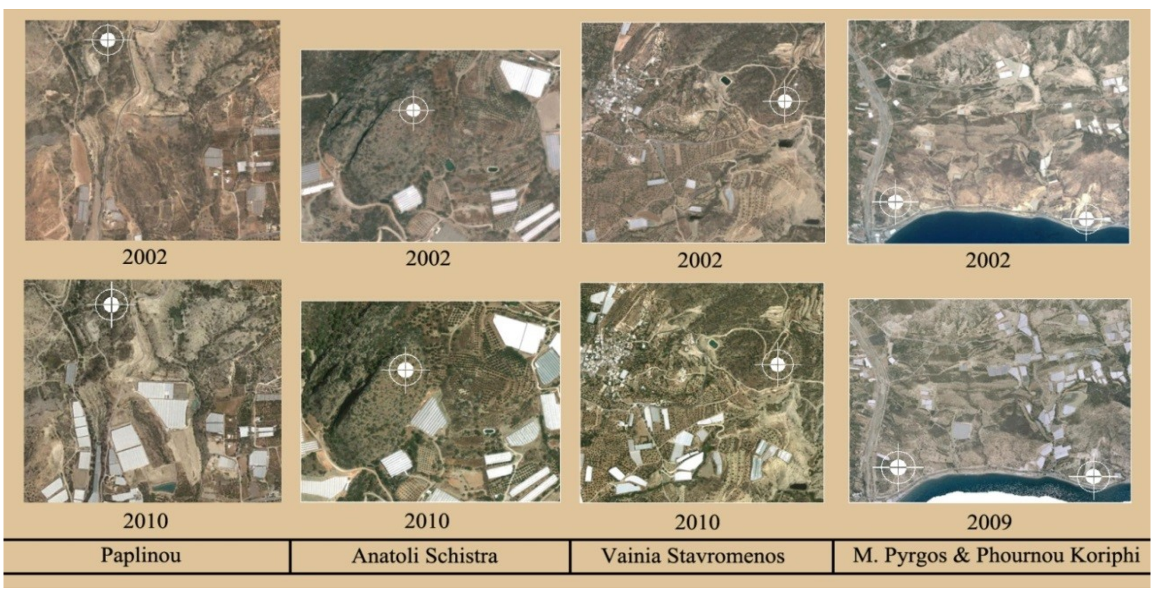

Figure 4 Archaeological sites in the Ierapetra region that have been affected by greenhouse expansion (Source: Google Earth and National Cadastre Agency)

of Stavromenos and within a 700 m radius from the site (Fig. 4). Anatoli Schistra, a Final Neolithic site, built on a rocky knoll ca. 1km south of the village of Anatoli is located in a landscape of rocky pinnacles that had suffered minimum human intervention until about 20 years ago (Nowicki 2002, 32). The lack of arable land in the lowland plains forced many farmers to build their greenhouses in higher elevations, often intruding into areas that were previously forested or used for animal grazing, and seasonal farming. Satellite images show that from 2002 until 2010, 6 new greenhouses were added to the landscape within a 500 m radius from the site (Fig. 4).

Paplinou, a small Final Neolithic site in the periphery of our study area, is another example of the rapid landscape transformation that took place in the area over the past 20 years (Nowicki 2002, 29). The site, consisting of a dense pottery scatter, is located in an arid area dotted with barren hills, suitable for greenhouse agriculture. Satellite imagery between 2002 and 2010 shows how a hill located ca. 300 m south of the site was almost completely leveled. The area that is now covered with greenhouses measures approximately 250 x 400 m in size (Fig. 4). Unfortunately, sites like Paplinou can be easily destroyed during such large-scale projects because they consist only of pottery sherds and are lacking architectural features, often visible on the surface. West of our study area are the sites of Myrtos Phournou Koriphi and Myrtos Pyrgos (Fig. 3).

Both settlements, located along the southern coast, are of great importance for the settlement history of the Ierapetra area. The sites were excavated during the 1960's and 1970's and provided significant evidence for human activity in the area from the Early Minoan II period until the Late Minoan IB period (Warren 1972, Cadogan 1977–1978). Satellite imagery from Google Earth and the National Cadastre Agency demonstrates how between 2002 and 2009 the land immediately north of Myrtos Phournou Koriphi and less around Myrtos Pyrgos was heavily exploited for greenhouse agriculture with the construction of at least 10 new greenhouses within a period of 7 years (Fig. 4). Even though both sites are known to the local population and are considered sightseeing attractions in the Ierapetra region, the intensive exploitation of the surrounding landscape has inevitably altered their cultural "hinterland" and could have potentially affected smaller satellite sites that were dependent on the larger settlements along the coast.

The third step of the project was to map the greenhouse coverage around Ierapetra, and determine how much of the coastal valley is inaccessible for archaeological fieldwork. Later, several components were added such as industrial and residential areas as well as landfills and quarries. Greenhouse units and other land features were mapped using mainly open source desktop GIS applications (Fig. 5). Google Earth was used during the initial stage for the mapping of individual greenhouses by creating several layers of colored polygons. The majority of mapped areas (ca. 75%) were later recorded on the ground with GPS for accuracy-checking purposes. Our data shows that most mapped greenhouses had an error margin –compared with the Google positioning– of 2–3 m for most cases which was sufficient enough for our study. These layers were saved as kmz files and later converted into GIS files with QGIS. With some polygon calculations we were able to perform mathematical operations and extract different types of information such as land coverage by greenhouses in ha, percentage of the Ierapetra coastal valley covered by greenhouses, surface coverage by modern settlements, etc. (Fig. 6).

With the available mapping technology we went a step further and created a preliminary cultural vulnerability map for the southern part of the Ierapetra Isthmus (Fig. 7).

Vulnerability maps have been developed and used in several fields of science and decision making including hazard management (crisis mapping), social services distribution and most recently in climate change (Golobič and Žaucer 2010, Edwards *et al.* 2007, Akram 2005). Such thematic maps reveal the degree to which a region is likely to be exposed to various harming factors according to a hypothetical disaster scenario. The common goal is to use such information in order to develop a reaction plan for the protection of endangered areas.

In our case, we wanted to measure how vulnerable archaeological sites (known and potential) could be due to their proximity to greenhouses as well as modern settlements and industrial areas. Since we have no extensive data of how fast the greenhouses expand across the coastal valley of Ierapetra it was necessary to construct a hypothetical concept of creating buffer zones around the actual greenhouses and estimating how vulnerable cultural sites could be in the future due to their location adjacent to greenhouses (starting from the observation that new greenhouses were usually built close-by previous ones). Judging from a few sites that we studied over a period of 8–9 years we realized that proximity to a greenhouse is a key factor and increases the risk for the preservation and well-being of a site.

Since there has been no systematic survey of archaeological sites in the region all areas around greenhouses were considered risk zones. The above-mentioned archaeological sites demonstrate how proximity to greenhouses can have different effects for cultural sites ranging from complete destruction (Apostolakou 1998) to partial coverage of a site's catchment area.

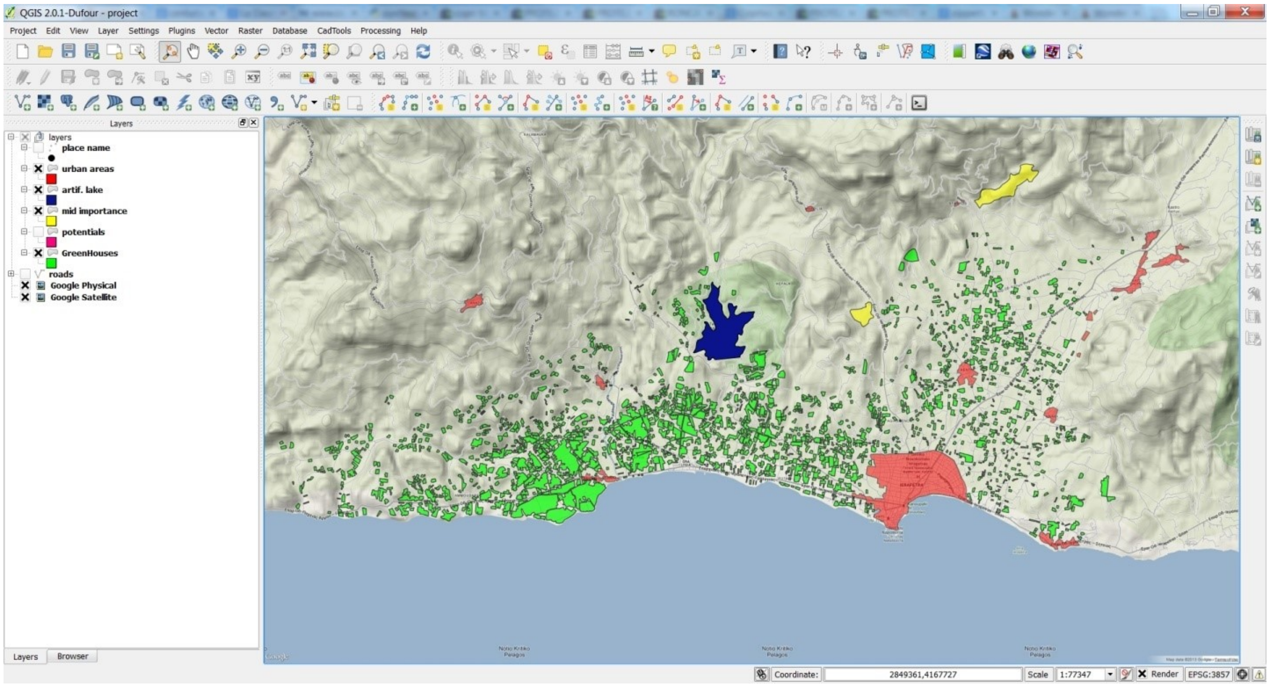

Figure 5 Using QGIS to map greenhouse distribution in the Ierapetra area

Type of coverage	Coverage in ha (area surveyed is 7186 ha large)	Percentage of overall coverage
Greenhouses	978 ha 9.78 km²	13.6%
Water dam, land fills, quarries	101 ha 1.01 km²	1.4%
Modern settlement	276 ha 2.76 km²	3.8%
Total coverage:	1355 ha 13.550 km²	18.8%

Figure 6 Preliminary evaluation of geospatial data for the southern Ierapetra Isthmus.

For this project we used a table to register the risk group and the objects that are vulnerable. Consequences were estimated on a scale of five buffer zones, with 1=low risk (500 m from the greenhouse), 2=limited (400 m), 3=serious (300 m), 4=very serious (200 m) and 5=catastrophic (100 m). In order to indicate the different levels of risk on the map we used different hues of yellow, orange, and red, with red for catastrophic and yellow for low risk (Fig. 7).

Our vulnerability assessment map allowed us to detect the areas that are under immediate threat from greenhouse expansion. Further, it showed us which cultural landscapes demonstrate potential for archaeological research in the future. Since most of the coastal valley has been largely affected by agricultural activities it is necessary that archaeologists focus on other areas in order to explore the settlement history of the Ierapetra region. Several regions, including the Meseleroi mountain range, the West Siteia Mountains, and the Kalamafka Mountains, have escaped the dramatic and rapid landscape transformations around Ierapetra. One of these unspoiled landscapes is Chryssi Island, located only 15 km south of Ierapetra. Archaeological survey and excavation on the island from 2008–2010 produced substantial data regarding the diachronic use of the island and how it reflected changes in settlement patterns that occurred along the south coast of Crete and more specifically in the region of Ierapetra (Chalikias 2013, Apostolakou *et al.* 2012). Cultural landscapes like Chryssi enhance our understanding of the regional settlement history even though they are located on the margins of the Ierapetra region.

The project, generally outlined here, is at a very preliminary stage, and there are still many issues regarding the recording and documentation of archaeological sites in areas that have suffered by modern human intervention. We hope to present our results to the 24th Ephorate of Prehistoric and Classical Antiquities, the Department of Environment and Spatial Planning on Crete, the Directorate of Agricultural Economy on Crete, as well as the municipality authorities of Ierapetra in order to initiate a discussion on how to implement and design a strategic plan for the protection of the remaining cultural sites in the southern part of the Ierapetra Isthmus. More importantly, farmers in the Ierapetra area need to become aware of the long-term value of the physical and cultural landscape surrounding them and how their actions can sometimes have a negative effect on the nearby cultural sites. Even though satellite imagery combined with geospatial data can be a powerful tool in visualizing landscape transformation, it is only effective when such results can be used actively in policy making decisions concerning modern land use and the protection of our cultural heritage.

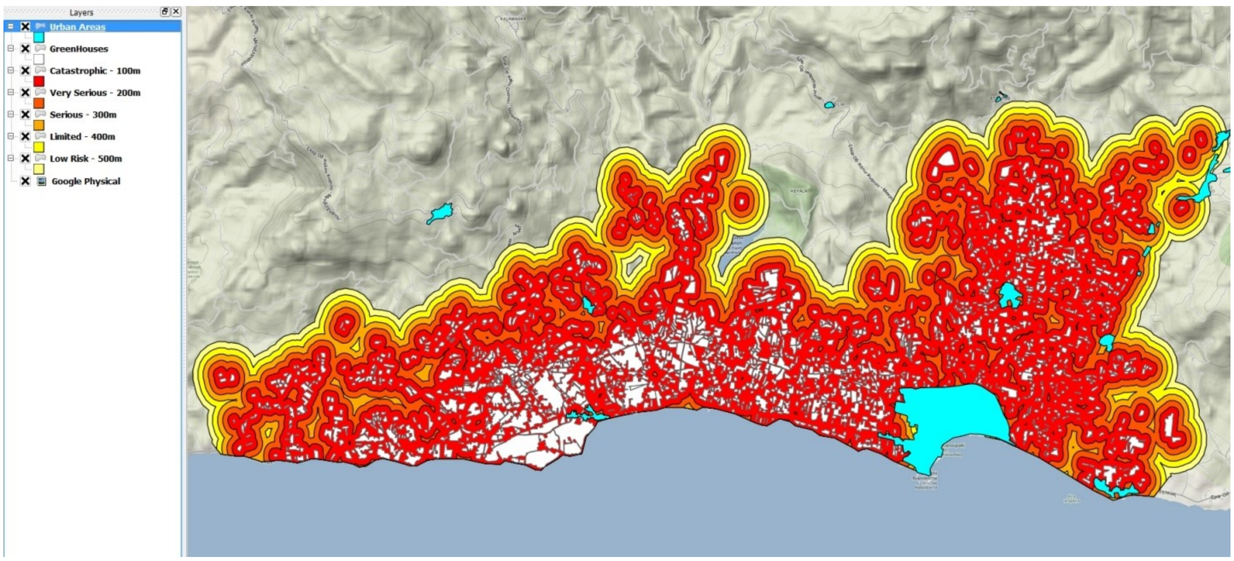

Figure 7 Cultural vulnerability map for the southern Ierapetra Isthmus based on distance from the nearest greenhouse.

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