Digital pasts for the present

Proceedings of the 2nd Conference on
Computer Applications and Quantitative Methods in Archaeology
Greek Chapter (CAA-GR)

Athens, 20-21 December 2016

Edited by

Giorgos Vavouranakis, Markos Katsianis,
Yiannis Papadatos, Marlen Mouliou and Platon Petridis

National and Kapodistrian
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FOREWORD - DIGITAL PASTS FOR THE PRESENT

The 2nd CAA-GR conference

The organisation of the 2nd CAA-GR conference in Athens aimed to keep up the momentum that had been created by the inaugural CAA-GR 2014 conference. Athens was chosen as it provided a vivid location for widening the CAA-GR outreach with the participation of academics, researchers, professionals in the public and private sectors, students and further audience interested in digital heritage applications. Despite the limited means available, conference participation was kept as open as possible. In addition, K. Papadopoulos, E. Kotoula and K. G. Akoglu and G. Cantoro kindly agreed to teach two workshops on "Computational Imaging for Cultural Heritage" and "Historical landscapes through Aerial Photogrammetry" respectively.

The conference received 31 oral and 10 poster presentations by 110 participants, representing universities and research centres, public institutions and private bodies (learned societies, cultural foundations and heritage companies) in Greece and abroad. Another 75 people registered for the conference, alongside a significant number of postgraduate and undergraduate students from the hosting institution, many of whom provided their help towards the seamless organisation of the meeting. J. Pakkanen kindly agreed to deliver the keynote presentation on the use of computer applications in the Kyllene Harbour Project.

Participants had the chance to attend and discuss new research either completed or in progress, that showcased novel digital methods and touched upon many thematic areas on the contemporary study, measurement, interpretation and presentation of the past. The conference was significant in mapping applied research into digital heritage issues in Greece and neighbouring countries during a period of economic recession that on the one hand affected the means by which to conduct research, while on the other hand has led to the appraisal of the economic potential of digital cultural heritage. In this respect, much of the conference value lies in the discussions generated among participants, in bringing people with shared interests together and in the overall opportunity to advance ideas that will allow the creation of yet new digital pasts for the everlasting present.

About this publication

The present volume contains 21 contributions in English or Greek that have been reviewed by our international scientific committee and grouped by the editors into four thematic areas. Contributions range from long papers for completed projects to short papers for work in progress with preliminary results. The remaining contains a brief review of the contributions organised by thematic category and a closing note on the state of research as manifested from the contents of this volume.

Recording methods and data modelling for fieldwork and laboratory work

The first section of the volume contains five papers that address different issues of data recording in the field and in the laboratory. *Murray et al.* present their experience in the integration of 3D documentation procedures into landscape based intensive pedestrian survey workflows. In the context of the Mazi Archaeological Project (MAP) airborne (drone) and terrestrial photogrammetry methods were used for the creation of detailed and complete 3D models of structures encountered in the field. *Eleftheriou et al.* give a thorough account of the geometric documentation procedures employed on the World Heritage site of the Acropolis of Athens, in the framework of the ongoing restoration and conservation interventions. Digital photogrammetric techniques and laser scanning are used on monuments components and individual architectural members for the rapid and accurate documentation of both geometry and texture before and after restoration. *Valchev and Bakardzhiev* describe a GPS assisted field survey in Boyadzhik, Bulgaria. Although the discussion is limited to the description of individual archaeological features and material culture recovered, it provides one of the first examples of digitally assisted fieldwork at the landscape level in the country. *Christaki et al.* shift the conversation towards the intra-site level by advancing formal ontological representations of the knowledge process involved in the documentation of an archaeological building excavation, using as an example the West House of the archaeological site of Akrotiri, Thera. Their analysis integrates key extensions with the core Conceptual Reference Model CIDOC CRM (ISO 21127) to allow a semantically concrete linkage of excavation recording and interpretative procedures with data on preserved architectural remains. Finally, Papageorgiou *et al.* employ artificial aging procedures on bone samples to monitor and define the effects of environmental factors on the physical and chemical decay of organic material.

This first section comprises of a rather diverse group of papers. Nevertheless, they all wish to integrate technological aspects within established research practices. *Murray et al.* adopt a balanced point of view as they both acknowledge the speed and efficiency of digital methods and highlight the cases that manifest the qualitative benefits of traditional draftsmanship. *Eleftheriou et al.* discuss geometric documentation procedures in relation to worksite limitations and project development logistics. *Valtsev and Bakardzhiev* present a case for the benefits of spatial recording at the landscape scale. *Christaki et al.* demonstrate the importance of clarifying the connections between people, objects and research activities for the development of explicit archaeological data models. Finally, *Papageorgiou et al.* remind us that the application of quantitative and statistical methods in laboratory controlled conditions can foster better understanding of physical and chemical processes.

Each paper stresses a different instance of the same phenomenon, that the application of technology should target more effective documentation practices and take into account already established operational workflows. By assessing the performance of a method or a tool in real conditions, novel solutions can be explored. In this respect, the above cases exhibit that the application of digital solutions and quantitative research, if viewed with a critical stance, can help towards improving, extending or even revising existing implementations. This realisation coincides well with calls for the "critical appreciation of computational artefacts" within the "context of the developing archaeological digital ecosystem" as Huggett (2017) suggests.

GIS, remote sensing & geospatial modelling

A second group of four papers is related to GIS and geospatial modelling containing useful case studies. *Alexandrakis et al.* provide an interesting case on the integration of geomorphological data with archaeological evidence to model the transformation of the coastal zone of Ammoudara in northern Crete from a diachronic point of view. Their results not only provide a geomorphopological reconstruction at the landscape level, but they are also used to explore landscape and population dynamics. *Argyriou and Sarris* target the development of enhanced models on ancient water management planning. By integrating multiple calculated geomorphological derivatives from large scale DEMs with Least Cost Path analysis, they are able to improve the prediction of water resource routes for Eastern Crete in successive stages in the Bronze Age and suggest locations with high archaeological potential. In a similar manner, *Noviello et al.* assess the performance of different probability distribution models in validating site locations with multiple environmental variables. Using as a test case the well investigated area of Tavoliere Plain in Italy they manifest the efficiency of Species Distribution Modelling procedures adopted from ecological modelling to archaeological predictive modelling. Finally, *Agapiou and Lysandrou* discuss the potential of satellite and remote sensing techniques in the detection of ancient tombs looting in the Politico area in Cyprus. By combining high resolution multispectral satellite and aerial images, they clearly demonstrate the benefit of collating remote sensing data with archival images and in situ investigation in a GIS environment for the systematic monitoring of areas with archaeological potential against illegal activities.

All the above papers employ data integration and multivariate statistics to achieve more informative and precise models of present and past terrain features. The fusion of diverse data sources and supplementary geospatial procedures in archaeolandscape studies has been marked by Sarris and Dederix (2014) as a general trend in the field. A lot of factors have contributed towards this end: New satellite products come with high resolution allowing for more precise geomorphological measurements; drone mapping contributes to the fast and accurate compilation of small scale geospatial datasets; open source spatial data collections are becoming increasingly available; archival sources are re-appreciated and incorporated as digital data; processing requirements for advanced multi-variate modelling procedures are becoming less complex and time-consuming.

The results from these modelling exercises are employed to infer past human behaviour as well as to inform archaeological investigation and cultural protection strategies at the landscape level. Although the examples presented here do not break the legacy of focusing mainly on environmental variables, they attempt to overcome these limitations by integrating archaeological sources of information, calculating more revealing geomorphological derivatives and testing alternative algorithms to assess their predictive results. In addition, an emphasis is placed on groundtruthing as well as on the correlation of modelling results with existing knowledge to verify their validity and performance. These aspects indicate a shift within GIS modelling applications towards data inclusive studies that target pattern recognition for informed decision making. In this perspective, the presented examples demonstrate that the integration of old and new, environmental and cultural, low and high resolution spatial data collections alongside their analysis using novel, holistic, diverse and multi-variate approaches can provide a trailhead towards more timely and insightful spatial applications in the cultural domain.

3D modelling, virtual reality & simulations

A third group of six papers is related to the field of virtual reconstructions both of buildings and of artefacts. *Manzetti* proposes a revised reconstruction of the Roman theatre at Gortyna, Crete, through architectural acoustics, namely the ability of buildings to reflect and/or absorb sound. The related affordances of the extant theatre remains are compared to models of optimal sound dissemination. *Stamatopoulos and Anagnostopoulos* propose a method for the virtual reconstruction of pottery vessels out of sherds. This method is based on the calculation of potter's wheels marks in relation to changes in wall thickness. *Hein et al.* have reconstructed a prehistoric pottery kiln from Rhodes in order to afford a detailed study of firing techniques and to reach a better understanding of pottery production technologies in the Aegean during the Late Bronze Age. *Kartaki* has employed computed tomography in order to create a virtual archive of a 17^{th} century AD casket, which has helped her identify its raw materials and, mostly, document its condition. This technique may evidently assist conservators greatly. *Moullou et al.* attempted to simulate the lighting conditions in the interior of past dwellings in order to assess whether ancient weavers would afford proper working conditions. This research has combined the experimental reconstruction of lamps with the virtual simulation of closed spaces with reference to the remains of the ancient city of Olynthus. The authors argue that the light was not enough, especially if weavers were to identify different colours and thus they probably based their work more on their experience than on their ability to see. Finally, *Kormann et al.* present a virtual reconstruction of an Early Helladic 'Corridor House' found at Helike in the northwest Peloponnese accompanied by a digital terrain model of the area. These reconstructions assisted the examination of the structural strength of the Corridor House.

Despite the thematic diversity, all six papers share several common threads, which concern the current status of simulation and modelling research. One such point of convergence is related to the epistemological status of virtual reconstructions. More than two decades of research have established that visualisations are not simply the end products of research. As they render buildings, artefacts and processes of the past visible, they facilitate the combination of information about them and thus become active parts in the production of further knowledge about the past. Therefore, each virtual model is inherently related to its metadata, paradata and the wider research framework that produced it. This principle is well demonstrated by all the aforementioned papers, as virtual reconstructions are well embedded in their specific research themes. In at least half of the six papers, these images are only intermediary steps of the research process. The other three papers have a reconstruction as their major aim, be that of a building, such as the Roman theatre of Gortyna or of artefacts, such as pottery vessels or the 17^{th} century casket. It is interesting to note that none of the six papers demonstrate an explicit interest in the realism or authenticity of the images produced.

Indeed, it has been argued that simulations are not and should not be treated as faithful substitutes of a past reality. After all, any simulation is literally different than its prototype. Since part of the past is forever gone and non-retrievable, models may at best operate as a 'prosthesis'. This term has been coined by Shanks and Webmoor (2013) in order to compare past material remains with an amputated human body and the virtual reconstruction of such remains with an artificial limb. The addition of the latter will never bring back the amputated body to its former condition. Nevertheless, it may give a close idea how this body looked and functioned before the loss of the limb. Chrysanthi *et al*. (2012) have among others proceeded further along this line of argument. They have suggested that different types of prosthesis give equally different types of impressions. The selection of the right type then depends on the research question and its meticulous documentation rather than on what may at first seem to empirically fit more to the past remains themselves. This proposition closes the argument on the use and importance of 3D modelling and VR simulations, as it focuses again on their embeddedness within the epistemological framework of a wider research framework. It also underlines that the validity of any type of reconstruction is judged according to its role in research and not by itself; a principle demonstrated by all six papers.

Users and interfaces: education, museums and multimedia

The last section deals with the interpretation and enhancement of cultural heritage through digital applications easily accessible by the broad public. *Morandini's* paper on Brescia's archaeological heritage describes the utilisation of sources from archaeological and conservation interventions within an impressive set of technologies (graphic reconstructions, AR and VR solutions) as a novel method to enhance the visualisation and appreciation of ancient architecture and decoration in urban archaeological sites. *Papadakis et al.* present the use of "casual games" and AR in the interpretation of Zea's ancient shipsheds, an almost forgotten place encircled by modern construction in Piraeus. Their application (Urban Game [BETA]) engages the visitors to a series of quests through which they progressively acquire information about the remains and their history, while an AR application showcasing the remaining architectural features complements visitor experience.

Antonakakis et al. present the underlying modelling processes that resulted in the virtual reality production for dome projection, entitled "Hagia Sophia: 1500 years of History". Tackling questions of digital reconstruction accuracy combined with real time production technical limitations and the desire for enhanced spectator interactivity, the authors provide a well-documented implementation example. *Vosnidi's* contribution deals with a more "traditional" approach to cultural e-learning through digital media targeting young audiences. The new digital platform of the Byzantine and Christian Museum of Athens is open to different audience categories offering distant access to the museum's highlights. Attention has been given to the educational applications, simple games and questions for children urging them to experience a real visit to the museum.

Athanasoulis et al. present their project on the digital enhancement of more than 100 eastern Peloponnesian castles. Targeting public awareness and heritage protection a web-platform was developed, offering historical and architectural information for each castle, full photographic coverage, including cases with 3D content, while additional applications allow user interaction targeting different age and educational levels. The last paper by *Koukopoulos and Koukopoulos* opens the discussion about user participation in digital cultural heritage environments. The design and implementation of "Culture Gate", a prototype digital participatory platform is presented, providing digital services focused on public archaeology. The platform proposes community based data collection and dissemination to the broader public as well as data exchange inside a restricted research community touching on issues of authoring, noise detection, privacy and data security.

In total, this group manifests that enhanced cultural content combined with digital equipment and interactive media are increasingly becoming a necessity for cultural institutions to attract new and younger audiences. Especially the latter are much more familiar with web-based technologies and mobile electronic devices, as they are natives in the world of digital interaction and this feature certainly raises the standards of cultural services. Digital applications are becoming a key component of an institution's ability to attract more visitors, sustain its reputation and perpetuate its activity, not least through efficient revenue generation. Towards this end, digital applications for heritage consumption do not restrict themselves to standard solutions any more, such as websites and e-content. They increasingly adopt novel approaches including AR content, casual gaming and they accentuate their footprints on different social media platforms. Obviously, not all institutions ingest technology with the same rate, while the range of solutions for the presentation of cultural heritage to the public is ever-expanding.

A general trend of the papers included here is the establishment of well-tested media solutions, such as 3D reconstructions and videos. These constitute the baseline for building more complex implementations, such as augmented reality, that require advanced and frequently expensive hardware and software solutions. However, it appears that successful heritage interpretation and presentation lie not so much in the actual technological innovation, but rather in the underlying content curation methods that should respect authenticity, communicate meaning, facilitate appreciation and encourage inclusiveness (Champion 2014). Systematic and detailed archaeological and historical research leads to informed representations of cultural heritage, while it also provides the necessary ingredients to advance indulging scenarios and deploy the appropriate technological solutions for an immersive user experience.

Conclusions

To sum up, the second CAA-GR conference presented the latest progress in computer applications and quantitative methods in archaeology in Greece and beyond. The wide spectrum of applications, methods, approaches and primary subject matter of the contributions in this volume provides a representative mapping of current research in the field that reflects current trends at the international level. In this respect, it furnishes a necessary localised addition to the annual international CAA conference proceedings.

An active interest in all aspects of computer applications and quantitative approaches is manifested including the documentation and analysis of field and primary data, GIS modelling and prospection research, 3D reconstruction and modelling, as well as the conservation of past remains and the dissemination of archaeological knowledge both to the specialists and, foremost, to the wider public. The latter seems to be an increasingly dominating field of research interest, and although many domains of computer applications in archaeology are not underrepresented, this rise seems to be the outcome of a leading edge in of 3D data acquisition, in combination with technological developments of 3D content consumption by the entertainment, tourism and cultural industries.

What is even more important to our opinion, however, is the noticeable presence of theoretical reflection and the related focus on the applications themselves, the types of analysis they allow and the results they have produced. Several of the papers presented here have managed to consider aspects of methodology, operational limitations and technological bias. In addition, most papers viewed their research results as stemming from a mediated thinking through and with the tool, which may be argued to be a way forward in the field of digital archaeology and heritage studies.

This may well be the aftertaste of the second CAA-GR conference, which now passes the torch to the 3rd CAA-GR conference to be held in 2018 in Cyprus. We wish to close this Forward by thanking the CAA-GR Board, the National and Kapodistrian University of Athens, the Institute for Mediterranean Studies - Foundation for Research and Technology Hellas, the Society for Aegean Prehistory - Aegeus and Dipylon - Society for the Study of Ancient Topography, the Norwegian Institute at Athens and the Irish Institute of Hellenic Studies at Athens and the rest of the academic and financial sponsors of the conference, the workshop instructors (K. Papadopoulos, E. Kotoula, K. G. Akoglu and G. Cantoro), all the students who helped before, during and after the conference, all referrees, M. Zoitopoulos for the editing and pagination assistance and V. Papazikou who kindly agreed to have her work titled "Digital Stratigraphies" featured on the book cover.

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RECORDING METHODS AND DATA MODELLING
FOR FIELDWORK AND LABORATORY WORK

NEW AND TRADITIONAL METHODS FOR THOROUGH DOCUMENTATION AND ANALYSIS OF ARCHITECTURAL FEATURES IN THE GREEK LANDSCAPE: A CASE STUDY FROM THE MAZI ARCHAEOLOGICAL PROJECT (WESTERN ATTICA)

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Περίληψη/Abstract

Μέχρι πρότινος, η επαρκής, ακριβής και υψηλής ανάλυσης αποτύπωση των αρχιτεκτονικών καταλοίπων που απαντώνται σε ολόκληρη την ελληνική ύπαιθρο δεν ήταν ένας άμεσα επιτεύξιμος στόχος για τα προγράμματα εντατικής επιφανειακής έρευνας. Η σχεδίαση μικρών, διάσπαρτων ευρημάτων είναι χρονοβόρα, ακόμη και για έμπειρο προσωπικό, και για μία διεξοδική αρχιτεκτονική αποτύπωση είναι απαραίτητα χωρικά δεδομένα υψηλής ακρίβειας που είναι δύσκολο να είναι προσβάσιμα σε απομακρυσμένα σημεία της υπαίθρου. Εξάλλου για την ολοκλήρωση της σχεδιαστικής αποτύπωσης ακίνητων ευρημάτων πολύ μεγάλων διαστάσεων, όπως οι οχυρώσεις, είναι αρκετά δύσκολο να διατεθούν πλήρεις αρχιτεκτονικές σχεδιαστικές ομάδες για ολόκληρες περιόδους έρευνας. Εν τούτοις, η τεχνολογική πρόοδος καθιστά δυνατή και ταυτόχρονα σύντομη και επαρκή την παραγωγή τρισδιάστατων αποδόσεων τόσο μικρών όσο και μεγάλων αρχιτεκτονικών στοιχείων με ακρίβεια και πιστότητα. Παρά ταύτα, η ψηφιακή καταγραφή δεν αποτελεί πανάκεια για την αποτύπωση ευρημάτων στις επιφανειακές έρευνες καθώς οι παραδοσιακές μέθοδοι παρέχουν ποιοτικώς διαφορετική πληροφόρηση και σε πολλές περιπτώσεις παραμένουν ίσως πιο σκόπιμες, ιδιαίτερα εκεί όπου η βλάστηση είναι πυκνή ή η διατήρηση των καταλοίπων είναι κακή.

Until recently, accurate, high-resolution, and efficient recording of architectural features encountered throughout the rural Greek landscape has not been a readily achievable goal for intensive pedestrian survey projects. Drawing small, scattered features is time-intensive, even for trained personnel, and proper architectural survey requires the acquisition of high-quality geodata that can be hard to come by in the remote countryside. On the other hand, drawing massive features, like fortresses, is sufficiently difficult to require independent architectural drafting teams entire seasons to complete. Technological advances, however, are increasingly making the production of precise and accurate 3D renderings of both small and large architectural features not only possible, but rapid and efficient. Nevertheless, digital recording is no "silver bullet" for feature recording in surveys. Traditional methods provide qualitatively different information and in many cases may remain more expedient, especially where vegetation is thick or preservation is poor.

Keywords: Photogrammetry, Pedestrian Survey, Architectural Documentation, Fortifications

Introduction

The Mazi Archaeological Project (MAP) is a diachronic regional survey operating in the tradition of Mediterranean landscape archaeology, under the auspices of the Swiss School of Archaeology in Greece and the Ephorate of Antiquities of West Attica, Piraeus, and the Islands of the Greek Ministry of Culture (Fachard *et al.* 2015; Knodell *et al.* 2016, 2017a). The project employs intensive and extensive pedestrian survey methods to investigate a small mountain plain at an important crossroads on the border between Attica and Boeotia (Fig. 1), and to thereby contribute to the scholarly understanding of borderlands, especially in terms of material and human history. The project has also invested considerable time and energy into investigating the benefits and costs associated with the integration of new methods in the recording of archaeological features into the day-to-day process of architectural documentation.

The purpose of this paper is to describe the rationale, methods, and results of MAP's feature recording program from the 2015 and 2016 field seasons. First, we distinguish our approach to feature recording from the usual systems employed by pedestrian survey projects. Then, we outline the ways in which digital methods created new possibilities for survey feature recording, for both large and small features, in the context of the MAP survey. Finally, we consider the drawbacks of digital approaches to feature recording, and argue that in many cases manual draftsmanship remains a superior method of illustration, which should not be wholly or uncritically replaced by digital tools.

1. Feature Documentation in Intensive Pedestrian Survey

While photogrammetric modelling and RTK DGPS mapping for architectural documentation have been adopted with alacrity as part of the toolkits of Mediterranean archaeological excavations (Olsen *et al.* 2013; Roosevelt 2014), for the reconstruction of the physical landscape (Orengo *et al.* 2015), and at self-contained projects where the focus is the accurate architectural documentation of large structures (Sapirstein 2016), these techniques have not yet been brought to bear on the study of the ancient architectural landscape more broadly construed.

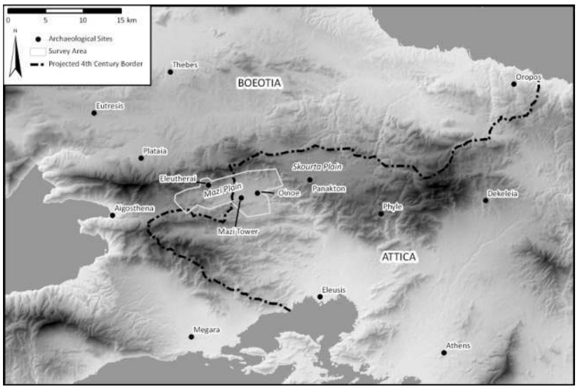

Figure 1 Mazi Archaeological Project survey region in the context of the mountainous Attic/Boeotian borderlands.

A common methodological dilemma confronted by Greek archaeologists involved in intensive survey projects is the problem of the "artefact-rich" environment (Caraher *et al.* 2006). However, less attention has been given to architectural features on intensive Mediterranean survey projects (an exception is the Saronic Harbors Archaeological Project, Tartaron *et al.* 2011; Clinton *et al.* 2014). The problem of how to manage the documentation and interpretation of a feature-rich landscape that is dense with ruined architectural structures (Fig. 2) has largely been left unexplored.

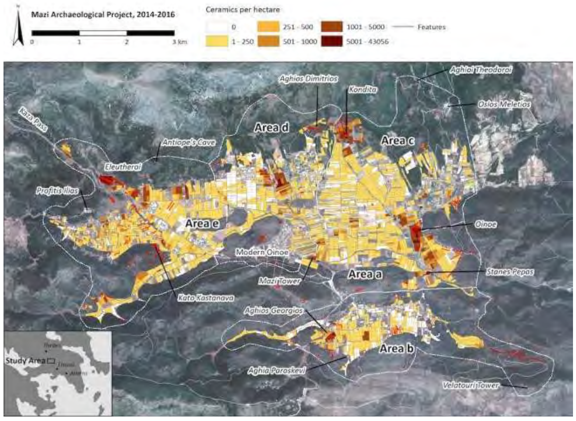

Figure 2 The quantity of features in the MAP survey represents a formidable assemblage of architectural ruins.

Features discovered during the process of fieldwalking in survey projects and previously known architectural monuments within survey areas have usually been documented on paper and in database entries, but physical recording has been limited to a few general photographs and rough sketches, which often do not include a precise scale and are not based on a proper architectural survey. This is understandable, given the limitations of time and effort archaeological teams face and the sheer quantity of ruined structures usually encountered during a season of exploring the landscape. Drawing small, scattered features is time-intensive, even for trained personnel, and proper architectural survey requires the acquisition of high-quality geodata that can be hard to come by in the remote countryside. Typical approaches to the issue have been either to treat features largely separately from the artefactual environment (Fachard 2016, 82–83) or to find a middle ground based on sketches, selective drawings, photography, and basic mapping (Berenfeld *et al.* 2016; Knodell *et al.* 2017b). On the other hand, drawing and planning massive features, like fortifications, is sufficiently difficult and time-consuming that independent architectural drafting teams require entire seasons to complete full documentation.

2. Documenting the Feature-rich Greek Countryside

At the Mazi Archaeological Project we have taken seriously the notion that architectural features encountered in field surveys should be recorded in greater detail than has become customary, and argue that in most cases a responsive combination of new technologies and traditional methods make this an achievable goal (see Douglass *et al.* 2015). During fieldwork in 2015 and 2016 MAP made extensive use of 3D recording to produce plans and elevations of several architectural features discovered during the survey. The features varied in size from the foundations of small structures to massive and well-preserved fortifications.

3D architectural documentation in the field proceeded in three steps. First, team members prepared the subject by clearing vegetation and placing coded photogrammetry targets, spaced approximately 1–2 m apart, in the scene. Second, ground control points, which would be used to assess the accuracy of the photogrammetric model and to tie the model into geographical space so that orthophotos extracted from the models could be loaded seamlessly into the project GIS, were measured. Since datums were not available in most areas of the survey, fixed points were measured using a Leica CS25 RTK DGPS unit receiving correction data from the Metrica SmartNet through a SIM card. Third, photos were taken with a Nikon D7100 DSLR camera equipped with a Zeiss 18 mm f/3.5 lens in accordance with standard methods for archaeological photogrammetry, which have been described elsewhere (Olsen *et al.* 2013; Green *et al.* 2014; Sapirstein 2016). The camera was raised on a fiberglass boom for overhead shots when required (Sapirstein 2016, Fig. 3).

Figure 3 MAP team members documenting the Velatouri Tower using a fiberglass boom to raise the camera without the aid of a drone.

While archaeologists often use drones to record architectural features (Fernández-Hernandez *et al.* 2014), we chose to employ a predominantly terrestrial approach to photogrammetry in the field for a number of reasons. First, given the number of features involved and their remote locations, we felt that the limited battery life and unwieldiness of most commercial drones would have hindered the pace of our recording and therefore compromised our mission to be both thorough and comprehensive in the documentation of survey features. Second, since most features we needed to record were not large and did not stand above a few meters, the use of a drone would not have made recording faster or more effective (although there were exceptions: see section 2b below). Finally, most drones that are within the budget of the average field project do not support a payload that would allow them to carry cameras ideally suited to photogrammetric recording, i.e. cameras with large sensors and interchangeable lenses (Shortis *et al.* 2006). For detailed architectural recording of ruined features, then, drone-based photogrammetry is not always ideal (Sapirstein and Murray 2017).

2.a Small Features in the Landscape

The majority of architectural features encountered in the MAP survey area comprise the foundations of small structures, which are usually recorded in a summary fashion by field survey projects because the time it would take to draw and survey them in detail is not merited by the information that they provide. The typical dataset that results from feature recording in the context of survey projects is therefore usually made up of quick snapshots and rough sketches. As Figures 4a and 4b demonstrate, neither product provides much meaningful information to the researcher hoping to study the feature-rich landscape. Two-dimensional photographs of poorly-preserved foundations taken from ground level are usually difficult to parse from the point of view of an architectural historian, and sketches by inexpert field team members are not done to scale and do not accurately represent the construction materials and their organisation.

One of our goals at MAP was to consider how much effort and time it would require to enhance the typical workflow for feature recording in survey projects using digital methods beyond photography. In experiments in the field during the 2015 season, the MAP team documented the foundations of small structures that are typical of features encountered throughout the Greek landscape in the field in approximately twenty minutes. This amount of time is not significantly more than is usually required for team members to sketch, photograph, geolocate, and take notes on a feature, but the result is a 3D model and georectified orthophoto that provide a clear view of the feature that is much easier to understand and analyze than sketches and photographs (Fig. 4c; see www.maziplain.org for other examples). The recording process included clearing vegetation, placing targets, measuring control points, and shooting photos.

Since the amount of time needed to document small features using photogrammetry and DGPS was not significantly more than the time that a survey team would usually require to sketch, take notes on, and photograph a small feature, we believe that building such recording processes into survey workflows should be considered a viable option for projects like

MAP. The benefits of doing so are, in addition, analytically valuable. Photogrammetry and detailed mapping produce metrically accurate, interactive models of architectural remains that are more valuable for study than snapshots and sketches. Georectified orthophotos generated from such recording techniques can be useful for analysis in a variety of ways. For example, they can be pulled directly into a project GIS, taking the place of simple polylines or polygons that usually serve as placeholders for such features in the geospatial containers of survey projects. In addition, architectural historians can study the orthophotos side-by-side, allowing them to see clearly the development or nuances of local construction techniques and materials without visiting hundreds of features in sequence.

Figures 4a-c Products of different methods of recording features encountered in the landscape as demonstrated by MAP's iterative documentation of feature c_016, the foundation of a small rectangular structure.

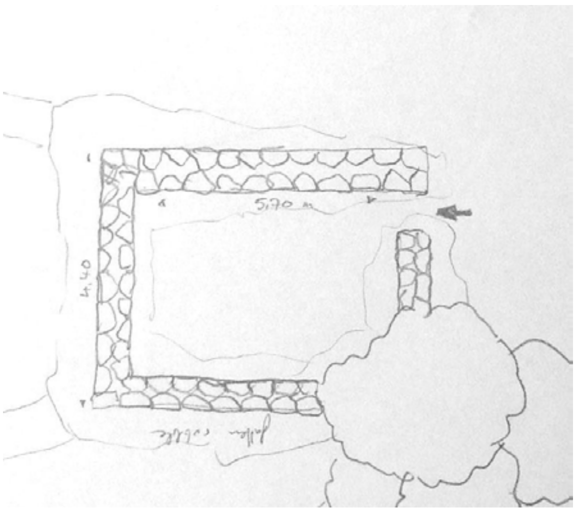

Figure 4a Rough sketch drawn by extensive survey team.

Figure 4b Feature photo facing east.

Figure 4c Top plan generated from a photogrammetric model and surveyed to 1.5 cm accuracy.

2.b Large Structures and Fortifications

A significant number of large stone towers, Byzantine churches, and fortification walls fall within the MAP survey area. These include the Classical/Hellenistic fortifications of Eleutherai and Oinoe, the Frankish tower at Kondita, the churches of Aghia Paraskevi and Agioi Theodoroi (among many others), and the remains of several self-standing Classical/Hellenistic towers, most notably the relatively well-preserved one at the Velatouri hill (Fig. 5).

Figure 5 Snapshot of the 3D model of the Velatouri Tower.

Due to their large size and the height of standing remains, the majority of these features have proven difficult to plan and draw properly (e.g. Ober 1985, plate 5 for Eleutherai, compared to Figure 6, the plan generated in MAP's 2016 field season). In the case of the fortress at Eleutherai, the generation of a stone-by-stone plan of the entire structure was not only challenging, but effectively impossible, prior to our project's use of computational assistance. This is primarily because the towers stand to such a formidable height that surveying them using the regular methods of architectural draftsmanship (that is to say, scaling the towers in order to measure datums and dimensions) is too dangerous and cumbersome to attempt.

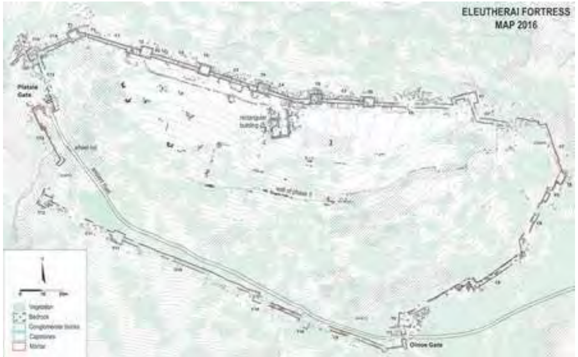

Figure 6 A new stone-by-stone plan of the fortress of Eleutherai.

Using a combination of drone and terrestrial photogrammetry, the MAP project has generated complete and detailed 3D models of these features which will provide useful analytical proxies during study seasons, freeing project staff up to spend more time thinking about the architecture as opposed to repeatedly visiting remote structures or spending additional study seasons drawing features in the field. At the same time, we wish to emphasize that electronic representations of architectural features are not necessarily interchangeable with architectural drawings by trained draftspersons, which present interpretative and analytical data that a "raw" photo recording cannot provide. We explore questions of how to weigh decisions about which sort of recording is best in the remainder of this paper.

3. Comparison of Traditional and 3D Recording Techniques

One way of comparing new and traditional methods is a simple measure of investment of time. How much faster and more efficient is 3D recording? While it is generally assumed that the adoption of digital methods increases the pace at which the documentation will proceed, detailed discussion and quantification of the precise drawbacks and advantages of 3D and traditional recording is not present in the existing literature. Figure 7 represents one attempt to estimate the rough savings in labour and costs based on approximate time needed to generate architectural drawings using manual and photogrammetric methods. These figures assume that the goal of recording is simply to document the presence and extent of features, rather than to interpret or generate final products for publication and dissemination. Estimates in Figure 7 are based on rates of hand-drawing Late Bronze Age buildings by the architectural documentation team at the Saronic Harbors Archaeological Research Project, while estimates for photogrammetric recording are based on work at MAP in the summers of 2015 and 2016. By comparing the time required to draft a pen and ink plan of architectural features with efficiency figures from recording using 3D methods, we demonstrate that the 3D recording method has the potential to be at least three times as efficient in the majority of cases, and therefore might free up significant time for analysis of architecture in the field.

Nonetheless, our experience shows that photogrammetric feature recording is often not a suitable option for the recording of features discovered during field survey. At MAP, this was true in cases where vegetation was especially thick or impossible to remove, or when complex renderings, such as sections through standing structures, were required. One of the most important lessons learned from our work in the Mazi plain is that clearing vegetation is often the most time-consuming part of 3D recording in survey projects.

Vegetation must be cleared from a feature before it can be photographed for the purposes of digital modelling not only for the obvious reason that the vegetation obscures the architecture, but also because branches, leaves, and grasses blow in the wind, moving around and therefore changing the composition of the scene across the photo set. This variation will interfere with structure-from-motion software, which works by matching pixels in photographs taken of the same subject from different positions and therefore should be avoided to ensure jobs will be processed successfully in the lab. Because survey projects are designed in part to rediscover ruins that have been forgotten in the landscape for centuries or millennia, the remains encountered in a survey are often badly overgrown.

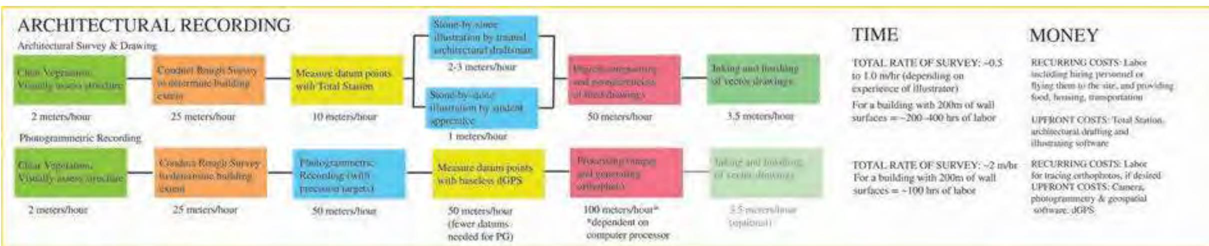

Figure 7 An attempt to quantify labour and cost savings that go along with the adoption of digital architectural recording.

Survey teams seeking to integrate photogrammetric recording into their research design must take into account the labour and time that will be needed to clear weeds and shrubs. Moreover, in some cases, this requires a special authorisation, as well as the approval of the local Fire Department.

Terrestrial photogrammetric modelling is also not an ideal way to record structures that are particularly poorly preserved, with large gaps in the architecture between which grassy fields or other "blank" zones intervene. Once again, the processing software struggles to stitch together architectural elements that are separated by vegetation that has few distinguishing features and that blows around in the wind. Especially large features of this nature might be more successfully recorded using UAV (drone) photography, although the resolution of the models will suffer depending on the camera and elevation of the flight.

In some cases it is simply easier and faster for an architect or trained illustrator to draw structures that are heavily overgrown or discontinuous by hand. At MAP, for example, an early Christian basilica in the settlement at Eleutherai is enshrouded in thick vegetation, including not only undergrowth but also trees (Fig. 8). Because the structure was quarried in early modern times and is extensive in size it presents an inconvenient subject for terrestrial photogrammetry even in the best of circumstances, since the large open spaces of the aisles and areas of robbed stone would hinder efficient stitching of the model, unless special preparation of the site with many coded targets were undertaken. In the case of the documentation of the basilica, it was obvious to the MAP team that a trained architectural draftsperson could draw an accurate and thorough plan of the architecture in less time than it would take to prepare the site for photogrammetric recording and to conduct the photography (Fig. 9).

Figure 8 Remains of an early Christian basilica at the settlement Eleutherai, which was too overgrown to be a suitable target for photogrammetric recording.

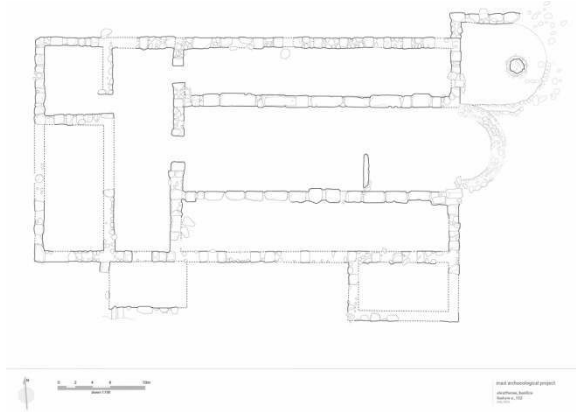

Figure 9 A basilica drawn using established methods of architectural drafting.

In some cases, then, recording features by hand will remain more effective and more efficient than digital recording for purely logistical reasons. Regardless of these considerations of efficiency, should digital recording always be the "first" option, with paper draftsmanship implemented only when conditions render digital recording inexpedient? This is a question that can only be answered after a careful consideration of the fundamentally different kinds of thinking both methods require archaeologists to undertake and the different kinds of products that they generate.

Drawing features by hand requires the archaeologist to approach the subject using different cognitive engines than the ones used by archaeologists recording features with cameras and drones. The process of digital recording is largely one of making the correct technical decisions. How many photos must be taken, and at what distance from the subject? How many scale bars or control points should be included in the scene? Is the lighting correct, or should photography be delayed until conditions are more favorable? Making these decisions does not require the recorder to look at or think carefully about the subject as an architectural feature.

The process of drawing, by contrast, requires both the technical expertise of a draftsperson and the analytical skills of an experienced architectural historian. Drawing is a process of careful interpretation and editing and therefore provides information of a qualitatively different value than 3D and 2D products that result from digital recording methods. While both approaches are designed to, at the most basic level, provide an accurate representation of what exists for the archive of the archaeological record, the process of manual recording on site requires the draftsperson to make decisions about what to include and what not to include. These drawings therefore carry interpretive value in addition to representing the dimensions and characteristics of features as they are encountered in the landscape.

Architectural draftsmanship is, then, a qualitatively different approach to recording and therefore cannot be replaced by digital methods in any substantive way, even though digital methods may often provide expedient tools for recording information in certain circumstances. There is no way to quantify the deep knowledge that a draftsperson gains about a subject during the hours often required to draw a feature. This investment in time often yields an understanding of a feature's materiality, embeddedness in its landscape, and relationships with nearby structures that cannot be achieved during the brief time that a photogrammetry expert will spend taking photographs and GPS points.

Our experiences confirm the notion that digital recording techniques can increase the speed and efficiency of feature documentation practices in intensive survey projects. The judicious application of these techniques will in many cases allow survey projects to create unprecedentedly rich and high-resolution data archives of the built ruined landscape. However, digital methods are not suitable for all recording tasks that feature documentation teams will encounter in a diverse architectural landscape. Furthermore, the process of digital recording does not replicate the process of drawing. Survey teams should think carefully about the implications that all-digital recording processes may have on the depth and quality of their knowledge of the built environment. The key to the proper deployment of tools and methods will always remain the experienced judgment of experts and team members, without programmatic or dogmatic adherence to a single approach to feature recording.

Conclusions

The approach to architectural feature recording and presentation taken at MAP represents a step forward in Mediterranean survey methods. Creating 3D models of major architectural monuments allows team members to study these remote, often difficult-to-reach features from anywhere, and in many cases from vantage points which would be difficult to reach otherwise. In addition, the use of photogrammetric recording can enhance the quality of recording for small features scattered throughout the landscape without costing field teams significantly in terms of time and labour expenditures. In some cases, however, traditional drawing techniques remain preferable, especially when architectural remains are poorly preserved or heavily overgrown. Moreover, these different methods record qualitatively different information, since drawing is an interpretive act. Survey projects outfitted with the equipment and personnel to integrate both methods can reasonably expect to create an unprecedentedly thorough documentation of architecturally rich landscapes without stretching either budgets or the investment of labour.

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ΕΦΑΡΜΟΓΗ ΣΥΓΧΡΟΝΩΝ ΜΕΘΟΔΩΝ ΑΠΟΤΥΠΩΣΗΣ ΣΤΗΝ ΤΕΚΜΗΡΙΩΣΗ ΤΗΣ ΒΟΡΕΙΟΔΥΤΙΚΗΣ ΓΩΝΙΑΣ ΤΟΥ ΠΑΡΘΕΝΩΝΑ

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Περίληψη/Abstract

Το πρώτο βήμα στη διαδικασία της αποκατάστασης ενός μνημείου είναι η ακριβής γεωμετρική τεκμηρίωσή του. Η φωτογραμμετρία, μία από τις ταχύτερες τοπογραφικές μεθόδους γεωμετρικής τεκμηρίωσης, χρησιμοποιήθηκε από πολύ νωρίς για την αποτύπωση μνημείων, ιστορικών κτιρίων και συνόλων, άλλωστε ένα από τα θέματα συζήτησης κατά την πρώτη συνεδρίαση της νεοσύστατης Επιτροπής Συντηρήσεως Μνημείων Ακροπόλεως το 1975, ήταν και η φωτογραμμετρική αποτύπωση των μνημείων και του χώρου της Αθηναϊκής Ακρόπολης. Τα τελευταία χρόνια, ιδιαίτερη έμφαση έχει δοθεί στη χρήση σύγχρονων μέσων και μεθόδων τεκμηρίωσης στην αποτύπωση των μνημείων της Ακρόπολης, των περιμετρικών Τειχών και του Βράχου, η οποία επέτρεψε την παραγωγή ορθοφωτομωσαϊκών και τρισδιάστατων μοντέλων με υφή υψηλής ποιότητας και ακρίβειας. Στο πλαίσιο της παρούσας ανακοίνωσης, περιγράφουμε την γεωμετρική τεκμηρίωση της ΒΔ γωνίας του Παρθενώνα με τη χρήση σύγχρονων μέσων και μεθόδων τεκμηρίωσης καθώς και τα ζητήματα που αντιμετωπίσαμε. Επιπλέον θα αναλύσουμε διεξοδικά όλες εκείνες τις παραμέτρους που πρέπει να συνεκτιμούνται προκειμένου να επιτευχθεί η επιθυμητή γεωμετρική ακρίβεια.

The first step in the process of restoration of a monument is its precise geometric documentation. Photogrammetry is one of the quickest topographic methods of geometric documentation, which was used very early for the recording of monuments, historical buildings and sites. Moreover, one of the issues discussed during the first meeting of the Committee for the Conservation of the Acropolis Monuments (ESMA) – when it was newly founded in 1975 – was the photogrammetric documentation of the monuments and the site of the Athenian Acropolis. In recent years, special emphasis has been placed on using techniques of advanced technology for the documentation of the Acropolis' monuments, the circuit wall and the bedrock. The development of digital photogrammetric techniques during the past years has made it possible to produce orthophotomosaics and three-dimensional models with texture of high quality and precision. The discussion will focus on the geometric documentation of the NW corner of Parthenon using contemporary methods of geometric documentation and the issues we faced. In addition, we will analyse extensively, all the parameters that should be taken under consideration, in order to achieve the desired geometric accuracy.

Λέξεις Κλειδιά: Φωτογραμμετρία, Τρισδιάστατη σάρωση, Τρισδιάστατη εκτύπωση, Ακρόπολη Αθηνών

Εισαγωγή

Η Ακρόπολη των Αθηνών αποτελεί ένα κορυφαίο μνημείο της παγκόσμιας πολιτιστικής κληρονομιάς, που αναστηλώθηκε επανειλημμένα στο παρελθόν, ενώ η συντήρηση, η αναστήλωση και η ανάδειξή του από το 1975 και εξής συνεχίζεται μέχρι σήμερα.

Οι σύγχρονες επεμβάσεις στα μνημεία έχουν απολέσει τον εμπειρισμό των παλαιότερων εποχών και οργανώνονται με βάση την επιστημονική προσέγγιση και τη δεοντολογία που απορρέει από διεθνείς συμβάσεις. Η γνώση του δομικού συστήματος και των υλικών κατασκευής αποτελεί βασική προϋπόθεση για την επιτυχή εφαρμογή νέων επεμβάσεων, την οργάνωση και επίβλεψη των οποίων έχει αναλάβει από το 1975 η Επιτροπή Συντηρήσεως Μνημείων Ακροπόλεως. Οι βασικές αρχές που ακολουθούνται είναι αυτές της Χάρτας της Βενετίας, όπου σύμφωνα με το άρθρο 9, η τεκμηρίωση αποτελεί βασική υποχρέωση στη διαδικασία της αποκατάστασης ενός μνημείου. Η ΕΣΜΑ από πολύ νωρίς, έδωσε ιδιαίτερο βάρος τόσο στο είδος και στις μεθόδους παραγωγής των τεκμηρίων όσο και στους τρόπους αποθήκευσης και διαχείρισής τους.

Το πλέον απαιτητικό είδος τεκμηρίων είναι τα προϊόντα της γεωμετρικής τεκμηρίωσης τα οποία κατά κύριο λόγο πρέπει να είναι σωστά και ακριβή και δευτερευόντως να είναι εκμεταλλεύσιμα σε εκπαιδευτικές δράσεις που απευθύνονται σε μαθητές ή στο ευρύ κοινό. Έτσι, παράλληλα με τις συμβατικές μεθόδους γεωμετρικής τεκμηρίωσης (μετρήσεις με συμβατικές μεθόδους, σχεδίαση, φωτογράφιση), η ΕΣΜΑ επεδίωξε την χρήση σύγχρονων μεθόδων αποτύπωσης υψηλής τεχνολογίας.

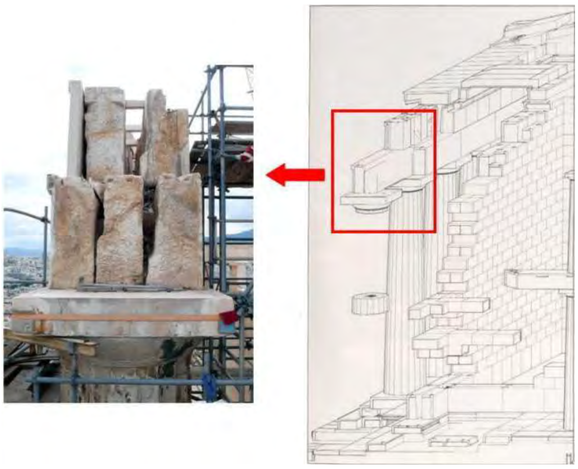
Η κατανόηση της δομής του μνημείων, η διατήρηση της τελειότητας της κατασκευής, η διαχείριση των φορτίων των αρχιτεκτονικών τους μελών, είναι μόνο μερικές από τις παραμέτρους που συνθέτουν το πλαίσιο των σύγχρονων επεμβάσεων στα μνημεία της Ακρόπολης. Μέσα σε αυτό το πλαίσιο, η ελαχιστοποίηση της διάρκειας της σχεδιαστικής και φωτογραφικής τεκμηρίωσης, η μεγάλη πιστότητα της απόδοσης της υπάρχουσας κατάστασης πριν και μετά τις επεμβάσεις και η υψηλή μετρητική ακρίβεια του παραγομένου προϊόντος επιτάσσουν σήμερα την χρήση μεθόδων όπως η **φωτογραμμετρία** και η **τρισδιάστατη σάρωση** για την παραγωγή ορθοφωτομωσαϊκών και τρισδιάστατων μοντέλων.

Το γεγονός ότι οι παραπάνω απεικονιστικές μέθοδοι εφαρμόστηκαν τα τελευταία χρόνια στα συγκεκριμένα μνημεία μεγίστης σημασίας και δυσκολίας στη προσέγγιση τους όπως ο Παρθενώνας, καθιστούν τα αποτελέσματα εντυπωσιακά, κυρίως γιατί έχει επιτευχθεί η επιθυμητή γεωμετρική ακρίβεια, που είναι της τάξης ελάχιστων χιλιοστομέτρων.

Τη διαδικασία και τα αποτελέσματα εφαρμογής των μεθόδων αυτών θα παρουσιάσουμε στη συνέχεια, με αφορμή τις εργασίες αποκατάστασης της ΒΔ γωνίας του Παρθενώνα.

1. Το κατασκευαστικό σύστημα και οι εκλεπτύνσεις του Παρθενώνα

Ο Παρθενών θεωρείται ως το πλέον αντιπροσωπευτικό παράδειγμα της αρχαίας ελληνικής αρχιτεκτονικής και αυτό το οφείλει στις ιδιαίτερες απαιτήσεις τόσο στο στάδιο του σχεδιασμού όσο και στο στάδιο της κατασκευής του. Το μνημείο αποτελείται από ανεξάρτητα μαρμάρινα στοιχεία (αρχιτεκτονικά μέλη), επιμελώς κατεργασμένα προκειμένου να έχουν πλήρη επαφή στους μεταξύ τους αρμούς, βασικό στοιχείο της εν ξηρώ δόμησης τους (Εικ. 1).



Εικόνα 1 Το δομικό σύστημα των αρχαίων μνημείων.

Και μόνο η επίτευξη της απολύτου εφαρμογής των όμορων επιφανειών ήταν μία πολύ απαιτητική και χρονοβόρα εργασία που στη πραγματικότητα ήταν πολυπλοκότερη, επειδή τα ομοειδή αρχιτεκτονικά μέλη δεν είχαν ακριβώς τις ίδιες διαστάσεις. Αυτές καθορίζονταν σε πρώτη φάση βάσει του γενικότερου σχεδίου κατασκευής του μνημείου, ενώ σε τελική διαμορφώνονταν επί τόπου στο μνημείο, με την λάξευση των αρχιτεκτονικών μελών κατά και μετά την οριστική τοποθέτηση τους.

Το σχέδιο του Παρθενώνα χαρακτηρίζεται επίσης από τις λεγόμενες οπτικές εκλεπτύνσεις, την διαμόρφωση δηλαδή ποικίλων καμπύλων γραμμών και επιφανειών στα επιμέρους στοιχεία του. Η μείωση, η ένταση αλλά και η εντονότερη κλίση των κιόνων προς το εσωτερικό του μνημείου, η σύμπτυξη των γωνιακών κιόνων και η καμπυλότητα όλων των οριζοντίων επιφανειών παράγουν ένα εξαιρετικά σύνθετο μοντέλο, στιβαρό και αισθητικά τέλειο, μοναδικό στην ιστορία της αρχιτεκτονικής. Ο Παρθενών επιπλέον είναι ο μεγαλύτερος ναός στην ελληνική επικράτεια και τα αρχιτεκτονικά του μέλη έχουν βάρος από 1 έως 11 τόνους.

2. Απαιτήσεις στην τεκμηρίωση του αναστηλωτικού έργου

Στο πλαίσιο των σύγχρονων επεμβάσεων, που πραγματοποιούνται για την αντιμετώπιση των βλαβών και την διάσωση του μνημείου, είναι αναγκαία, όπως προαναφέρθηκε, η σχεδιαστική και φωτογραφική τεκμηρίωση της υπάρχουσας κατάστασης των περιοχών του μνημείου που θα δεχθούν επεμβάσεις πριν και μετά από αυτές.

Η σχεδιαστική κυρίως τεκμηρίωση προ των επεμβάσεων είναι απαραίτητη προκειμένου να διαπιστωθεί το μέγεθος των μετακινήσεων και των παραμορφώσεων και να αποτιμηθεί ο βαθμός επικινδυνότητας για το μνημείο. Οι περιοχές που παρουσιάζουν τις μεγαλύτερες φθορές πρέπει να αποσυναρμολογηθούν, ώστε να αντιμετωπισθούν τα προβλήματα στο εσωτερικό της κατασκευής που πάντοτε αποκαλύπτονται κρισιμότερα του αναμενόμενου. Η αποτύπωση μετά την επέμβαση τεκμηριώνει την κατάσταση, η οποία θα αποτελέσει αναφορά στην μελλοντική παρακολούθηση του μνημείου. Η συγκριτική παράθεση της τεκμηρίωσης πριν και μετά τις επεμβάσεις, δείχνει το κατά πόσον κατά την ανασυναρμολόγηση των μελών επετεύχθη η επαναφορά τους στις αρχικές τους θέσεις, οπότε και η αποκατάσταση της κατασκευής στην αρχικές της διαστάσεις.

Καθοριστικός παράγοντας για την επιλογή του κατάλληλου μέσου αποτύπωσης είναι ο **χρόνος** που θα απαιτηθεί για την ολοκλήρωση της αποτύπωσης-τεκμηρίωσης. Ο χρόνος για τις επεμβάσεις σε μνημεία όπως ο Παρθενώνας πρέπει πάντα να είναι σύντομος, ώστε οι βλαμμένες περιοχές να αποσυναρμολογηθούν άμεσα. Επιπλέον είναι βέβαιο, ότι για διάφορους λόγους, όπως αυστηρών χρονοδιαγραμμάτων, χρηματοδότησης, αισθητικής όχλησης αλλά κυρίως για λόγους στατικής επάρκειας, το μνημείο δεν μπορεί να παραμένει ‘ανοικτό’ για μεγάλα χρονικά διαστήματα.

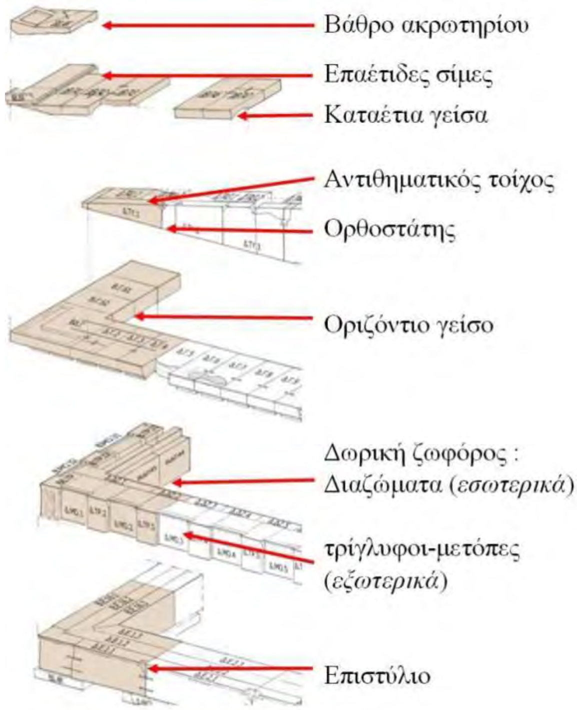
Ένας εξίσου σημαντικός παράγοντας επιλογής κατάλληλου μέσου αποτύπωσης είναι η απαιτούμενη **μεγάλη πιστότητα απόδοσης** της υπάρχουσας κατάστασης πριν ή μετά τις επεμβάσεις ώστε να δείχνονται με **υψηλή μετρητική** ακρίβεια τα υλικά, τα μορφολογικά και ρυθμολογικά στοιχεία, όπως οι αποκλίσεις των γεωμετρικών στερεών από τη κανονικότητα και οι οπτικές εκλεπτύνσεις, αλλά και οι παραμορφώσεις του φορέα, οι ζημιές και οι νεώτερες επεμβάσεις στις επιφάνειες των αρχιτεκτονικών μελών.

3. Η δομή των γωνιών της δυτικής πλευράς

Η δυτική πλευρά του Παρθενώνα διατηρεί την πληρότητα και αυθεντικότητα της αρχαίας κατασκευής, χωρίς μεγάλες απώλειες αρχαίου υλικού, παρουσιάζει ωστόσο προβλήματα, οφειλόμενα σε φυσικά και ανθρωπογενή αίτια. Οι μεγαλύτερες δυσκολίες στη κατανόηση της δομής και στη διαχείριση των λίθων εντοπίζονται στις γωνίες. Στις περιοχές αυτές, που από την αρχική κατασκευή τους έπρεπε να είναι ενισχυμένες, τα αρχιτεκτονικά μέλη εμπλέκονται με σύνθετο τρόπο, είναι μεγαλύτερα και άρα βαρύτερα ενώ οι καμπύλες γραμμές των εκλεπτύνσεων γίνονται εντονότερες και επομένως τα αρχιτεκτονικά μέλη αποκτούν γεωμετρικά στερεά που αποκλίνουν περισσότερο από τα κανονικά.

Ταυτόχρονα στις γωνίες καταμετρώνται οι μεγαλύτερες διανοίξεις αρμών και μετακινήσεις μελών που έχουν προκληθεί στο μνημείο στη διάρκεια των αιώνων, λόγω σεισμικών κ.α. συμβάντων. Εύλογα επομένως, η αποτύπωση των αρχιτεκτονικών μελών των γωνιών του μνημείου παρουσιάζει την μεγαλύτερη δυσκολία, ενώ συγχρόνως απαιτεί και την μεγαλύτερη ακρίβεια.

Αναλυτικότερα, οι γωνίες της δυτικής πλευράς περιλαμβάνουν πάνω από τα κιονόκρανα των κιόνων, τις στρώσεις του θριγκού και των δύο άκρων του αετώματος. Ο θριγκός πάνω από τη στρώση των επιστυλίων, αποτελείται στην εξωτερική παρειά από τη δωρική ζωφόρο (με εναλλάξ τις τριγλύφους και τις μετόπες) και τα διαζώματα με τον θράνο στην εσωτερική. Η στρώση των οριζοντίων γείσων καλύπτει διαμπερώς τη δωρική ζωφόρο. Το υπερκείμενο αέτωμα αποτελείται εξωτερικά από τον ορθοστάτη και εσωτερικά τον αντιθηματικό τοίχο, δομημένο από σειρές λιθοπλίνθων. Τα δύο μέτωπα καλύπτονται διαμπερώς από τα καταέτια γείσα που στο δυτικό όριο τους φέρουν τις επαέτιδες σίμες και στο όριο των μακρών πλευρών, τους ηγεμόνες στρωτήρες (κεραμίδια). Τα εξώτατα μέλη των γωνιών είναι σύνθετα, όπως η γωνιακή επαέτιδα σίμη με τη συμφυή υδρορρόη (λεοντοκεφαλή), το ακραίο καταέτιο γείσο με συμφυή την απόληξη του τυμπάνου και το βάθρο ακρωτηρίου που επικάθεται της γωνιακής επαέτιδας σίμης (Εικ. 2).



Εικόνα 2 Δομή των γωνιών της δυτικής πλευράς.

4. Αποκατάσταση της ΒΔ γωνίας της δυτικής πλευράς

Σύμφωνα με το εγκεκριμένο πρόγραμμα επεμβάσεων, που υλοποιεί η Υπηρεσία Συντήρησης Μνημείων Ακρόπολης υπό την εποπτεία της ΕΣΜΑ, οι εργασίες στη δυτική πλευρά του Παρθενώνα έχουν επιμεριστεί σε 8 υποπρογράμματα, εκ των οποίων αυτά των δύο γωνιών ήταν τα πρώτα που χαρακτηρίστηκαν ως άμεσης προτεραιότητας.

Έτσι, κατά την περίοδο 2011-2015, στο πλαίσιο του έργου «Συντήρηση και Αναστήλωση των Μνημείων της Ακρόπολης» του ΕΣΠΑ, ΠΕΠ «Αττική 2007-2013» ξεκίνησαν, οι εργασίες αποκατάστασης της ΒΔ και ΝΔ γωνίας του θριγκού του Παρθενώνα, που ολοκληρώθηκαν εντός της προγραμματικής περιόδου. Λόγω των εμφανών προβλημάτων που παρουσίαζαν οι δύο γωνίες κρίθηκε αναγκαία η μερική αποσυναρμολόγηση των λίθων έως την στάθμη των επιστυλίων (Εικ. 3).

Κατά την υλοποίηση του προγράμματος της ΒΔ γωνίας που παρουσιάζεται αναλυτικότερα ως προς τη τεκμηρίωση, αποξηλώθηκαν, αποκαταστάθηκαν δομικά και επανατοποθετήθηκαν στο μνημείο, 63 αρχιτεκτονικά μέλη, ενώ εργασίες αποκατάστασης πραγματοποιήθηκαν επί τόπου στα όμορα τους μέλη που παρέμειναν στο μνημείο (Εικ. 4).

Εικόνα 3 Αποκατάσταση της ΒΔ και ΝΔ γωνίας του θριγκού του Παρθενώνα.

Εικόνα 4 Αποξήλωση ΒΔ γείσου.

5. Φωτογραμμετρική αποτύπωση της ΒΔ γωνίας του Παρθενώνα

Στο πλαίσιο του έργου «Συντήρηση και Αναστήλωση των Μνημείων της Ακρόπολης» προκηρύχτηκε διεθνής δημόσιος διαγωνισμός με ανοικτή διαδικασία με σκοπό την επιλογή αναδόχου για την εκπόνηση μελέτης Τοπογραφικών και Φωτογραμμετρικών Αποτυπώσεων στην Ακρόπολη των Αθηνών. Αντικείμενο του έργου ήταν η πλήρης και ακριβής γεωμετρική τεκμηρίωση τμημάτων του Παρθενώνα, των Προπυλαίων και του ναού της Αθηνάς Νίκης. Αναλυτικότερα:

Στον Παρθενώνα

- η φωτογραμμετρική αποτύπωση των λίθων του θριγκού στη ΒΔ και στην ΝΔ γωνία σε κάτοψη σε κλίμακες 1:20 και 1:10.
- η παραγωγή ακριβούς ψηφιακού ορθο-φωτομωσαϊκού (true orthophoto) της κάτοψης της βόρειας πλευράς και της όψης του θριγκού της βόρειας πλευράς του μνημείου, με χρήση δεδομένων που θα δόθηκαν από την Υπηρεσία σε κλίμακα 1:20.

Στα Προπύλαια

- η φωτογραμμετρική αποτύπωση όλων των λίθων της νότιας πτέρυγας του μνημείου σε όψεις και σε κάτοψη σε κλίμακα 1:25.
- η φωτογραμμετρική αποτύπωση της κάτοψης του μνημείου σε κλίμακα 1:100.

Στο ναό Αθηνάς Νίκης

- η φωτογραμμετρική αποτύπωση της κάτοψης του μνημείου σε κλίμακα 1:100.

Η μελέτη εκπονήθηκε από την σύμπραξη «ΓΕΩΑΝΑΛΥΣΗ Α.Ε. – ΕΛΛΗΝΙΚΗ ΦΩΤΟ-ΓΡΑΜΜΕΤΡΙΚΗ Ε.Π.Ε. – ΦΩΤΟΠΟ Α.Ε» κατά το διάστημα 2012-2015.

Πιο συγκεκριμένα, στον Παρθενώνα προβλέπονταν η φωτογραμμετρική αποτύπωση σε κάτοψη των στρώσεων των λίθων του θριγκού στη ΒΔ και στην ΝΔ γωνία, περιοχές που βρίσκονται σε ύψος 13m περίπου από το δάπεδο του μνημείου. Οι μετρήσεις και οι λήψεις προβλέπονταν αμέσως μετά από την ολοκλήρωση των εργασιών αποσυναρμολόγησης ή επανατοποθέτησης σε κάθε οριζόντια στρώση. Τα τελικά παραδοτέα ήταν ακριβή ψηφιακά ορθοφωτομωσαϊκά (true orthophoto).

Η φωτογραμμετρική αποτύπωση στην ΒΔ γωνία του Παρθενώνα, πραγματοποιήθηκε πριν την καθαίρεση και μετά την επανατοποθέτηση, σε κλίμακα 1:20, για τις στρώσεις των κιονοκράνων, των επιστυλίων (Εικ. 5), των τριγλύφων – διαζωμάτων (Εικ. 6) και των οριζοντίων γείσων και για τη στρώση ορθοστάτη τυμπάνου – λιθοπλίνθων μόνο μετά την επανατοποθέτηση. Η τελική κάτοψη της ΒΔ γωνίας μετά την επανατοποθέτηση αποτυπώθηκε σε κλίμακα 1:10.

Το 2009 η κάτοψη της δυτικής πλευράς του Παρθενώνα είχε αποτυπωθεί από την Υπηρεσία σε κλίμακα 1:10 (Εικ. 7). Η λήψη των περίπου 600 φωτογραφιών που συνολικά χρησιμοποιήθηκαν, έγινε με ψηφιακή φωτογραφική μηχανή 12.8 Mp (full frame 48 x 36 mm, 4368 x 2912 pixels) με φακό 35 mm από μέσο ύψος 5 μέτρων (μέσο μέγεθος εικονοψηφίδας στο έδαφος 1.5 mm) και επικάλυψη μεγαλύτερη από 75% έτσι ώστε να μην υπάρχουν αποκρύψεις.

Εικόνα 5 Ορθοφωτομωσαϊκά της κάτοψης της στρώσης των επιστυλίων της ΒΔ γωνίας του Παρθενώνα, πριν και μετά την αποκατάσταση.

Εικόνα 6 Ορθοφωτομωσαϊκά της κάτοψης της στρώσης των τριγλύφων – διαζωμάτων της ΒΔ γωνίας του Παρθενώνα, πριν και μετά την αποκατάσταση.

Τα φωτοσταθερά που μετρήθηκαν ήταν τόσο προσημασμένα σημεία, όσο και σημεία λεπτο-μέρειας. Ο φωτοτριγωνισμός των εικόνων, για κάθε στρώση, επιλύθηκε με μέση τετραγωνική απόκλιση μικρότερη του 1 mm στα φωτοσταθερά.

Εικόνα 7 Ορθοφωτομωσαϊκά της κάτοψης της ΒΔ γωνίας του Παρθενώνα, πριν και μετά την αποκατάσταση.

Ωστόσο πέρα από τις μεγάλες απαιτήσεις ακρίβειας οι οποίες καθορίζονται από τη σπουδαιότητα του μνημείου, το έργο αυτό κατά την εκτέλεση του είχε σημαντικές ιδιαιτερότητες και δυσκολίες. Κατ' αρχάς το σχήμα των λίθων στις στρώσεις που αποτυπώθηκαν είναι εξαιρετικά πολύπλοκο, χαρακτηρίζεται από ακανόνιστες μεταβολές του αναγλύφου επιφάνειες παράλληλες στην διεύθυνση προβολής, έντονες ασυνέχειες, εσοχές και προεξοχές (Εικ. 8).

Εικόνα 8 Αρχικές εικόνες σε διάφορες στρώσεις.

Καθώς η τεκμηρίωση πραγματοποιήθηκε κατά την αναστήλωση του μνημείου, μεγάλα τμήματά του καλύπτονταν από ικριώματα. Το γεγονός αυτό επηρέασε καθοριστικά την εκτέλεση τόσο των μετρήσεων όσο των λήψεων. Οι λήψεις των εικόνων έπρεπε να είναι πυκνές, έτσι ώστε να εξασφαλιστεί ότι δεν θα υπάρχουν περιοχές που «κρύβονται» εξαιτίας της προοπτικής. Επιπλέον οι συνθήκες φωτισμού έπρεπε να είναι κατάλληλες για να μην υπάρχουν καθόλου σκιές. Η πρόσβαση στις προς αποτύπωση περιοχές εξασφαλίζονταν μέσω των ικριωμάτων εργασίας, τα οποία εξυπηρετούσαν και τις αναστηλωτικές εργασίες του προσωπικού της ΥΣΜΑ, υπήρχαν όμως και περιοχές που ήταν δύσκολα προσβάσιμες (Εικ. 9).

Εικόνα 9 Στιγμιότυπο από τις μετρήσεις.

Καθώς οι κλίμακες αποτύπωσης ήταν μεγάλες, 1:10 και 1:20, εκτός από τη γεωμετρική ακρίβεια, τα τελικά παραδοτέα όφειλαν να έχουν την αντίστοιχη οπτική ποιότητα έτσι ώστε να είναι αξιοποιήσιμα από τον τελικό αποδέκτη. Επιπλέον, αφού η αποτύπωση πραγματοποιήθηκε σε διαφορετικές φάσεις της αναστήλωσης του μνημείου, κάθε φορά έπρεπε να αποτυπώνονται κοινές αδιατάρακτες περιοχές και να μετρούνται τοποσταθερά σημεία που η θέση τους (οι συντεταγμένες τους) ήταν γνωστή με ακρίβεια μεγαλύτερη από αυτή της αποτύπωσης.

Τέλος κρίσιμη τόσο για την γεωμετρική ακρίβεια αλλά και για την οπτική ποιότητα της τελικής ορθοφωτογραφίας ήταν επίσης η ακριβής περιγραφή (μοντελοποίηση) της επιφάνειας του αντικειμένου, αλλά και η άριστη γνώση της γεωμετρίας του αντικειμένου που αποτυπώθηκε (Μαυρομάτη 2013).

6. Τρισδιάστατη σάρωση αρχιτεκτονικών μελών του θριγκού της ΒΔ γωνίας του Παρθενώνα

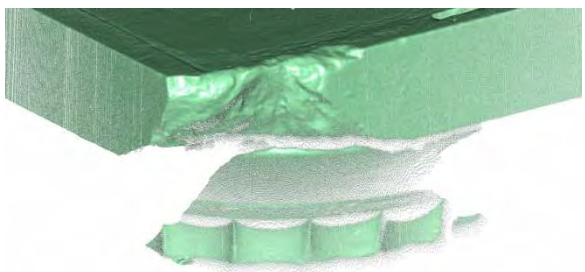
Παράλληλα με την φωτογραμμετρική αποτύπωση της ΒΔ γωνίας του Παρθενώνα, κατά την περίοδο 2011-2015, πραγματοποιήθηκε τρισδιάστατη σάρωση 55 αρχιτεκτονικών μελών του θριγκού με στόχο την πιστή γεωμετρική τεκμηρίωση τους, έπειτα από τις εργασίες αποσυναρμολόγησης και συντήρησης και πριν την επανατοποθέτησή τους στο μνημείο (Εικ. 10).

Εικόνα 10 Στιγμιότυπα από τις εργασίες 3D σάρωσης των αρχιτεκτονικών μελών.

Η τεχνολογία 3D καταγραφής με επίγειους σαρωτές laser επιτρέπει την ταχεία συλλογή μεγάλου αριθμού σημείων μιας επιφάνειας. Αποτελεί κατ' αυτόν τον τρόπο, ενδεδειγμένη τεχνολογία για την γεωμετρική τεκμηρίωση σχετικά μικρών αντικειμένων που μπορούν να μετακινηθούν και να τοποθετηθούν σε κατάλληλες θέσεις. Για να εξασφαλιστεί η πλήρης καταγραφή της γεωμετρίας των αρχιτεκτονικών μελών, αυτά τοποθετήθηκαν σε δύο τουλάχιστον θέσεις με την βοήθεια των δύο γερανών και του εξειδικευμένου προσωπικού της ΥΣΜΑ. Οι 3D σαρώσεις πραγματοποιήθηκαν στον Σηκό του Παρθενώνα, καθώς και στο εξωτερικό της Δυτικής και Βόρειας πλευράς του. Σε κάθε θέση το αντικείμενο σαρώθηκε από περισσότερες στάσεις ώστε να καταγραφούν περιοχές της επιφάνειας του, που αποκρύπτονταν λόγω του έντονου ανάγλυφου του. Για την διευκόλυνση και επιτάχυνση των εργασιών σάρωσης, τα μικρότερα αρχιτεκτονικά μέλη τοποθετήθηκαν σε ειδική περιστρεφόμενη πλατφόρμα. Ιδιαίτερη έμφαση δόθηκε ακόμα στον συντονισμό των εργασιών προκειμένου να μην δημιουργούνται καθυστερήσεις στην επανατοποθέτηση των αρχιτεκτονικών μελών.

Πιο συγκεκριμένα. οι 3D σαρώσεις πραγματοποιήθηκαν με σαρωτή laser "time of flight" που διαθέτει η Υ.Σ.Μ.Α. Η γεωμετρική ακρίβεια προσδιορισμού της θέσης μεμονωμένων σημείων είναι 6mm (σύμφωνα με τον κατασκευαστή) ενώ η γεωμετρική ακρίβεια των παραγόμενων 3D μοντέλων επιφάνειας (3D mesh models) είναι καλύτερη, της τάξης των 2 mm. Για κάθε αρχιτεκτονικό μέλος πραγματοποιήθηκαν 10 έως 15 μεμονωμένες σαρώσεις από διαφορετικές στάσεις, με πυκνότητα σημείων ανά 2mm, όση δηλαδή και η τυπική ακρίβεια του σαρωτή.

Τυπικό αποτέλεσμα κάθε σάρωσης είναι ένα πυκνό νέφος σημείων που περιγράφει την επιφάνεια του αντικειμένου (Εικ. 11). Ωστόσο, σε κάθε νέφος σημείων υπάρχουν αφενός κενά λόγω αποκρύψεων, αφετέρου εσφαλμένα σημεία στα όρια των αποκρύψεων, ενώ η πυκνότητα και η ποιότητα των μετρημένων σημείων δεν είναι ομοιόμορφη σε όλη την επιφάνεια του αντικειμένου λόγω της διαφορετικής απόστασης και γωνίας θέασης από τον σαρωτή.



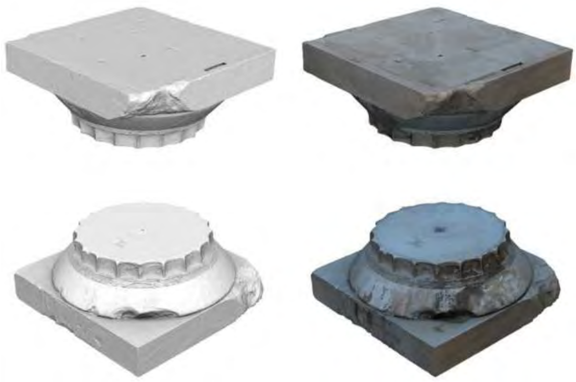
Εικόνα 11 Παράδειγμα νέφους σημείων από μία μεμονωμένη σάρωση.

Τα διακριτά νέφη σημείων (point clouds) που προέκυψαν, συνενώθηκαν αρχικά με επιλογή κοινών σημείων λεπτομερειών και στην συνέχεια με αλγόριθμους συνταύτισης επιφανειών. Ακόμα, με κατάλληλους αλγόριθμους επεξεργασίας τα ενιαία νέφη σημείων καθαρίστηκαν από θόρυβο και τριγωνίστηκαν ώστε να παραχθούν τα τελικά 3D μοντέλα των μελών, τα οποία αποτελούνται από 5 έως 10 εκατομμύρια τρίγωνα.

Τα παραγόμενα νέφη σημείων, παρότι διαθέτουν χρωματική πληροφορία, δεν εξασφαλίζουν από μόνα τους την απόδοση ενιαίας και υψηλής ποιότητας φωτογραφικής υφής στα τελικά 3D μοντέλα. Είναι έτσι απαραίτητος ο συνδυασμός 3D σάρωσης και Φωτογραμμετρίας (Serna *et al.* 2015, Zhang *et al.* 2006, Aguilera *et al.* 2006). Για τον σκοπό αυτό, ταυτόχρονα με την 3D σάρωση τα μέλη φωτογραφήθηκαν με ψηφιακή μηχανή ανάλυσης 20.3 MP ώστε να αποδοθεί βέλτιστη φωτογραφική υφή στα 3D μοντέλα επιφάνειας (Εικ. 12, 13). Οι λήψεις έγιναν από κατάλληλες θέσεις και απόσταση ώστε να διασφαλίζεται πολλαπλή επικάλυψη και εδαφοψηφίδα καλύτερη των 2 mm.

Οι εικόνες βαθμονομήθηκαν και προσανατολίστηκαν μέσω φωτοτριγωνισμών με την μέθοδο της δέσμης (bundle adjustment), με ομόλογα σημεία που μετρήθηκαν αυτόματα (Grammatikopoulos *et al.* 2015). Ως φωτοσταθερά χρησιμοποιήθηκαν φυσικά σημεία των μελών τα οποία εντοπίστηκαν και μετρήθηκαν τόσο στο 3D μοντέλο του σαρωτή όσο και στις εικόνες.

Εικόνα 12 Απόδοση φωτογραφικής υφής στο 3D μοντέλο τριγώνων (3D mesh model) από 70 περίπου επικαλυπτόμενες εικόνες.



Εικόνα 13 Απόδοση φωτογραφικής υφής στο 3D μοντέλο τριγώνων από 110 περίπου επικαλυπτόμενες εικόνες (αρχιτεκτονικό μέλος ΒΔ. ΚΚ.).

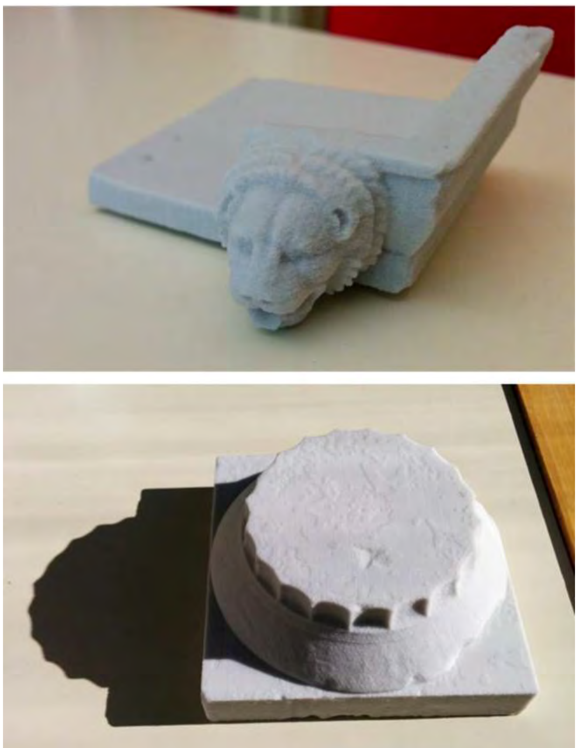
Στην συνέχεια, από τις προσανατολισμένες εικόνες αποδόθηκε φωτογραφική υφή στα 3D μοντέλα επιφανειών. Για τον σκοπό αυτό χρησιμοποιήθηκε κατάλληλος αλγόριθμος ο οποίος εντοπίζει αυτόματα τις εικόνες στις οποίες εμφανίζεται κάθε τρίγωνο του μοντέλου και το χρωματίζει με διαδικασία παρεμβολής χρώματος, ώστε να επιτυγχάνεται η οπτική συνέχεια του τελικού αποτελέσματος (Karras *et al.* 2007). Στις εικόνες 14, 15 και 16 παρουσιάζονται ορισμένα ενδεικτικά παραδείγματα φωτορεαλιστικών 3D μοντέλων που προέκυψαν με την παραπάνω μεθοδολογία.

Εικόνα 14 Παράδειγμα τελικού φωτορεαλιστικού 3D μοντέλου (αρχιτεκτονικό μέλος Δ.Ε. 1.1).

Εικόνα 15 Παράδειγμα τελικού φωτορεαλιστικού 3D μοντέλου (αρχιτεκτονικό μέλος Β.Ε. 16.1).

Εικόνα 16 Παράδειγμα τελικού φωτορεαλιστικού 3D μοντέλου (αρχιτεκτονικό μέλος Δ.Γ. 2).

Τέλος, η υπηρεσία προχώρησε στην δημιουργία αντιγράφων δύο αρχιτεκτονικών μελών σε κλίμακα 1:10 και 1:20 μέσω της τεχνολογίας της 3D εκτύπωσης. Για τον σκοπό αυτό τα 3D μοντέλα τριγώνων των μελών που προέκυψαν από την 3D σάρωση μετατράπηκαν σε κλειστά στερεά και κωδικοποιήθηκαν σε κατάλληλο τύπο αρχείου (Εικ. 17).



Εικόνα 17 3D εκτύπωση σε κλίμακα 1:20 του τελικού μοντέλου επιφάνειας που προέκυψε από την 3D σάρωση δύο αρχιτεκτονικών μελών.

7. Συμπεράσματα

Δεν γεννάται αμφιβολία ότι η σύγχρονη τεχνολογία παρέχει εργαλεία και προϊόντα τεκμηρίωσης αξιόπιστα και ειδικά στις αποτυπώσεις μεγάλης κλίμακας αναντικατάστατα. Ωστόσο προκειμένου να επιτευχθεί το αρτιότερο αποτέλεσμα, τεράστια σημασία έχει η συνεργασίας όλων των εμπλεκομένων και η εκ των πρότερων εκτίμηση και ανάλυση όλων των παραμέτρων.

Η φωτογραμμετρική αποτύπωση δίνει την δυνατότητα ταχείας συλλογής των δεδομένων υπαίθρου, χωρίς να προκαλεί σημαντικές καθυστερήσεις στο χρονοδιάγραμμα των αναστηλωτικών εργασιών, ιδιαίτερα όταν η αποτύπωση πραγματοποιείται σε διαφορετικές φάσεις της αναστήλωσης του μνημείου.

Ταυτόχρονα η φωτογραμμετρία, επιτρέπει την παραγωγή υποβάθρων ενιαίας ακρίβειας ανεξαρτήτως της έκτασης τους και της μορφολογίας τους ακόμα και σε περιοχές που δεν προσεγγίζονται.

Επιπλέον τα ορθοφωτομωσαϊκά συνδυάζουν τη γεωμετρική ακρίβεια του σχεδίου με την οπτική – ποιοτική πληροφορία της φωτογραφίας. Έτσι η τελική εξειδικευμένη ερμηνεία και σχεδίαση των ιδιαίτερων χαρακτηριστικών του αντικειμένου γίνεται από τον τελικό αποδέκτη, τον αρχιτέκτονα και τον αρχαιολόγο (Μαυρομάτη 2013).

Ωστόσο, τα σύγχρονα φωτογραμμετρικά προϊόντα υλοποιούνται από εξειδικευμένο προσωπικό και με ειδικό εξοπλισμό και απαιτούν σημαντικό χρόνο στην επεξεργασία των δεδομένων που αυξάνει ανάλογα με τον βαθμό της επιθυμητής γεωμετρικής ακρίβειας.

Η τεχνολογία της 3D σάρωσης επιτρέπει την γρήγορη και ακριβή καταγραφή της γεωμετρίας σύνθετων αντικειμένων. Ωστόσο σε πολλές περιπτώσεις δεν επαρκεί από μόνη της για την πλήρη και με ενιαία ακρίβεια αποτύπωση όλων των λεπτομερειών των προς αποτύπωση αντικειμένων. Το έντονο ανάγλυφο σε συνδυασμό με την δυσκολία τοποθέτησης του σαρωτή σε κατάλληλες θέσεις ώστε να καταγράφονται μετωπικά όλες οι περιοχές των αντικειμένων οδηγεί σε αποκρύψεις και κενά στα τελικά 3D μοντέλα, ιδιαίτερα σε μνημεία μεγάλου μεγέθους. Σε συνδυασμό όμως με την Φωτογραμμετρία είναι δυνατή η δημιουργία 3D μοντέλων επιφάνειας υψηλής και ομοιογενούς ακρίβειας και οπτικής ποιότητας.

Τέλος ανεξάρτητα από τη μέθοδο τεκμηρίωσης που θα επιλεγεί, φωτογραμμετρία ή 3D σάρωση θα πρέπει να ληφθούν σοβαρά υπ' όψιν και τα εξής: ο συντονισμός των πολλών ατόμων, διαφόρων ειδικοτήτων, που εμπλέκονται στην υλοποίηση των εργασιών, η διαχείριση του υλικού που παράγεται και η διαμόρφωση κοινών εργαλείων καταγραφής και διαχείρισης των πληροφοριών.

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CONCESION AREA "BOYADZHIK": A GPS ASSISTED SURVEY FOR THE PROTECTION OF CULTURAL HERITAGE

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Περίληψη/Abstract

Το 2011 ομάδα από το Περιφερειακό Μουσείο του Γιαμπόλ διενήργησε έρευνα αρχαιολογικών θέσεων στην περιοχή παραχώρησης "Μπογιατζίκ", η οποία βρίσκεται στο Δήμο Τούντζα και εκτείνεται σε 8,5 τετ. χιλ. στο έδαφος των χωριών Μπογιατζίκ, Γκαλαμπίντσι και Ζλατάρι. Σύμφωνα με τις περιβαλλοντικές συνθήκες χρησιμοποιήθηκαν εντατικές και εκτατικές ερευνητικές διαδικασίες. Η εντατική μέθοδος χρησιμοποιήθηκε στις περιπτώσεις όπου η ορατότητα στην επιφάνεια είναι πάνω από 50%. και ακολούθησε όσο το δυνατό σταθερότερο ρυθμό κατά την επιτόπια διερεύνηση του χώρου. Τα μέλη της ομάδας απείχαν μεταξύ τους έως 20 μέτρα. Κατά την εκτατική έρευνα η απόσταση διευρύνθηκε στα 25 μέτρα, καθώς αποτελεί τη μέγιστη επιτρεπόμενη απόσταση επικοινωνίας μεταξύ των μελών της ομάδας. Η έρευνα πεδίου αποκάλυψε οκτώ επίπεδους οικισμούς, ένα μοναστήρι και έναν τύμβο.

In 2011, a team from Regional historical museum inYambol, Bulgaria, carried out a field survey for archaeological sites in the concession area of Boyadzhik. The survey covered roughly 8.5 km^2 near the villages of Boyadzhik, Galabintsi and Zlatari in the Tundzha Municipality. Two field strategies, intensive and extensive, were employed during survey. Intensive survey was employed when visibility of material culture on the surface exceeded 50%. The members of the team followed a steady rate during their fieldwalk across the research area and were spaced 20 m. from each other. During the extensive survey, the walker spacing was increased to 25 m. – the maximum distance allowing easy communication. The team identified and documented eight open-air settlements, one monastery and one burial mound.

Keywords: Field Survey, Culture Heritage, Boyadzhik, Yambol

Introduction

In the autumn of 2011, a team from the Regional historical museum in Yambol investigated archaeological sites in the concession area known as Boyadzhik. The area of 8.5 sq. km. is found near the villages of Boyadzhik, Galabintsi and Zlatari in Yambol Municipality, Bulgaria (Бакърджиев, Вълчев 2012, 555).

The team from the Regional historical museum is amongst the first in Bulgaria to use of information technology in archaeology, having previously used various technologies during archaeological field surveys in 2008 under the Tundzha Regional Archaeological Project (TRAP). The international project based in Yambol region was led by Shawn Ross, Adela Sobotkova, Iliya Iliev and Stefan Bakardzhiev. The project aimed to document cultural heritage through non-destructive field methods, such as intensive field surveys aided by satellite remote sensing, mobile computing, relational databases and Geographic Information Systems (Iliev *et al.* 2012).

1. Methodology

The strategies used during the field survey were based on local environmental conditions. The team used both intensive and extensive surveys (Fig. 1).


Бояджик 2011 / Boyadzhik 2011 | Дата: / Date: | Време: / Weather: | СВ? / RP?
Обходен участък: / Survey unit: | Разстояние между обхождащите: 15м / Walk interval: 15m | Друго: / Other:
Тип на броене на фрагментите: Гъстота на м²/брой / Shard count type: Density per m²/Raw count
Обработка на земята: □Годишна □Перманентна □Пасище □Гора □Смесена □Друго / Land use: Annual Per Pasture Forest Disturbed Other
Земеделие: □Орница □Бранувана □Покарала □Узряла □Ожъната □Угар □Друго / Agr C: Plow Harrow Seedling Mature Harvest Fallow Other
Топография: / Topography: ○ Долина Valley btm ○ Склон Hillside ○ Вододел Ridgeline ○ Речна тераса Riv terrace
Образец? □ / Sample?
Наклон: / Slope: ○ Равен (<2%) Level ○ Слаб (2-15) Gentle ○ Стръмен (15-30) Steep ○ Много стръмен (30-45) Vr st ○ Невъзможно (> 45) Imp
Видимост: / Visibility: ○ >80% ○ 60-80% ○ 40-60% ○ 20-40% ○ <20%
Проходимост: / Pass: Л 2 3 4 Н / E 2 3 4 Im
Дренираност / Drain: C 2 3 4 M / D 2 3 4 W
Растителност / Veg: H 2 3 4 M / N 2 3 4 M
Камъни / Stone: H 2 3 4 M / N 2 3 4 M
Сянка / Shade: H 2 3 4 M / N 2 3 4 M
Бележки: / Notes: / Фрагментираност = / Frag =
Същото като по-долу? □ / Same as below?

Figure 1 Survey record sheet.

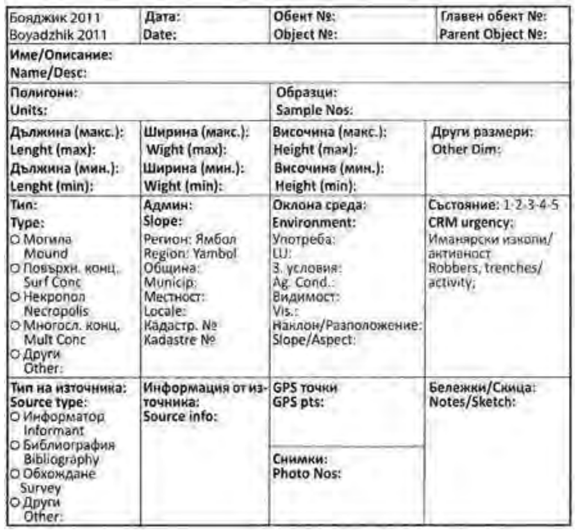
The first was employed when the visibility of the field surface exceeded 50%. The members of the team surveyed the territory at a steady rate using 20 m. walking spacing and 20 m. intervals between them, creating 20 x 20 m. investigation units. Artefacts were counted and recorded at the end of each unit. Diagnostic pottery pieces were collected and processed. Each polygon consisted of either 4 x 4 or 6 x 6 units depending on the participants.

In contrast, during the extensive survey the spacing between walkers was increased at 25 m., as this was the maximum distance allowing easy communication during fieldwalking (Iliev *et al*. 2012, 14-19).

All sites were documented using GPS. We used GPS points to show the approximate size of the archaeological site and its correct position on the geographic map. Analyses of the results help to determine areas with pottery concentration, which could be interpreted as potential archaeological features. Archaeological sites with no pottery were similarly recorded using GPS, photographs and textual descriptions, which included information on the condition of the site (Fig. 2).

2. Results

During the field survey in concession area Boyadzhik, 10 archaeological sites were registered: 8 settlements, a monastery and a burial mound (Fig. 3) (Бакърджиев, Вълчев 2012). The open-air settlements are presented from North-west to South-east.



Бояджик 2011 Boyadzhik 2011	Дата: Date:	Обект №: Object №:	Главен обект №: Parent Object №:
Име/Описание: Name/Desc:			
Полигони: Units:		Образци: Sample Nos:	
Дължина (макс.): Lenght (max): Дължина (мин.): Lenght (min):	Ширина (макс.): Wight (max): Ширина (мин.): Wight (min):	Височина (макс.): Height (max): Височина (мин.): Height (min):	Други размери: Other Dim:
Тип: Type: ○ Могила Mound ○ Повърхн. конц. Surf Conc ○ Некропол Necropolis ○ Многосл. конц. Mult Conc ○ Други Other:	Админ: Slope: Регион: Ямбол Region: Yambol Община: Municip: Местност: Locale: Кадастр. № Kadastre №	Оклона среда: Environment: Употреба: LU: З. условия: Ag. Cond.: Видимост: Vis.: Наклон/Разположение: Slope/Aspect:	Състояние: 1-2-3-4-5 CRM urgency: Иманярски изкопи/ активност Robbers, trenches/ activity;
Тип на източника: Source type: ○ Информатор Informant ○ Библиография Bibliography ○ Обхождане Survey ○ Други Other:	Информация от източника: Source info:	GPS точки GPS pts: Снимки: Photo Nos:	Бележки/Скица: Notes/Sketch:

Figure 2 Object record sheet.

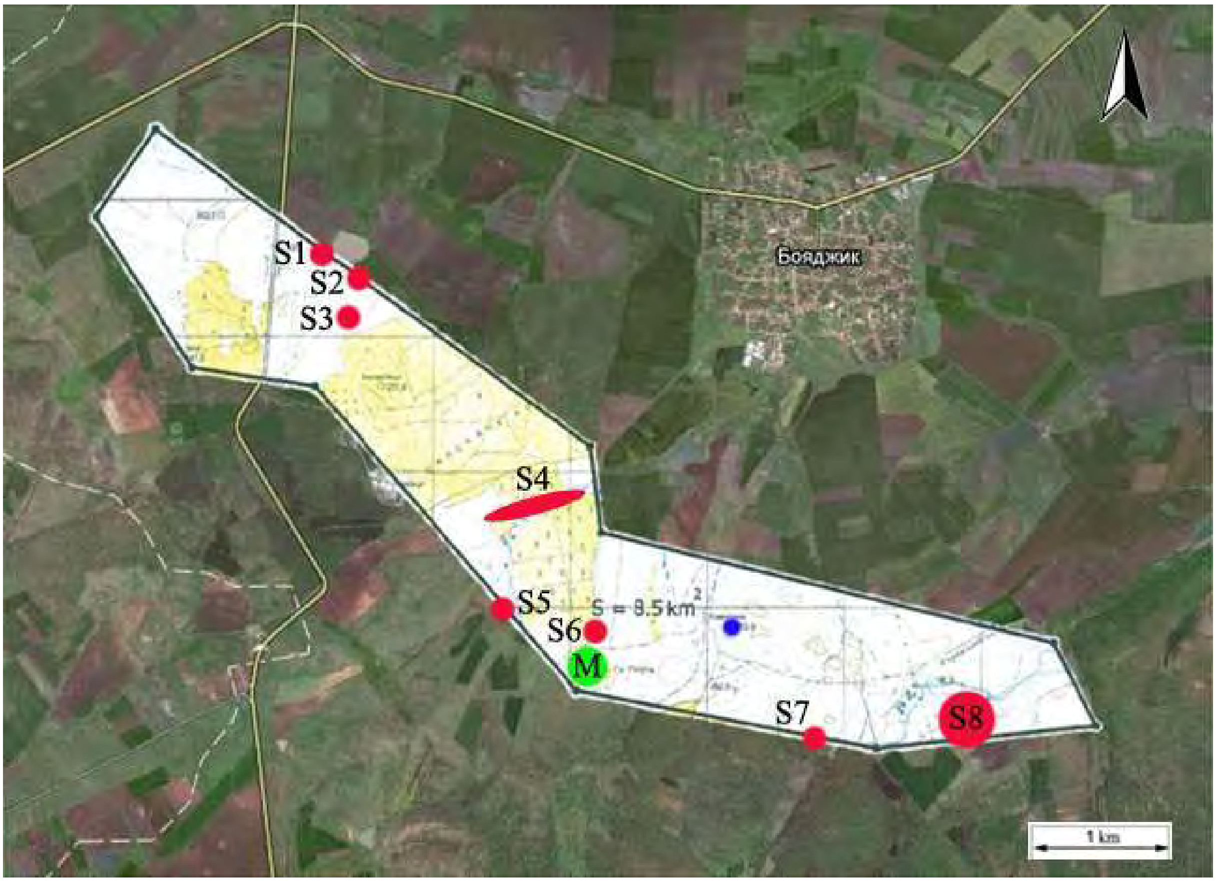


Figure 3 Concession area Boyadzhik with all archaeological sites (open-air settlements in red, medieval monastery in green and burial mound in blue).

Settlement 1 has an area of 0.4 ha. (Fig. 4). Pottery pieces from vessels covered with green or brown glaze were found. The ceramic material is typical for the Ottoman period (15th-16th centuries AD) (Плетньов 2004).

Settlement 2 has an area of 0.17 ha. (Fig. 5). The ceramic finds include pieces from plates and amphorae, dated in the period of the late Antiquity (4th-6th centuries AD) (Fig. 6) (Кузманов 1985). During the field survey, two flint tools were also retrieved (Fig. 6).

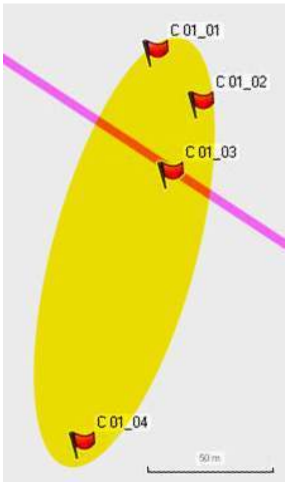


Figure 4 Area of settlement No 1.

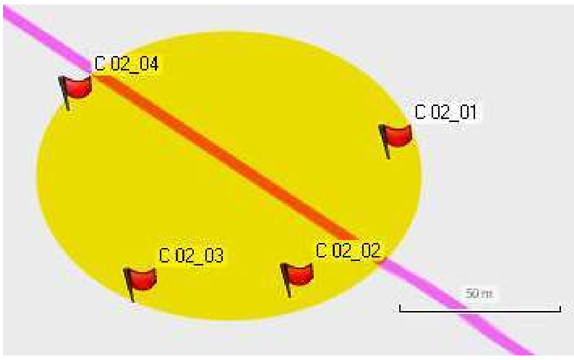


Figure 5 Area of settlement No 2.

Settlement 3 has an area of 0.4 ha. (Fig. 7). During the survey, the team found fragments from handmade and wheel-made pottery: pots, plates and storage vessels (Fig. 8-9). Some of them have decorations from incised lines or stick ornaments (Fig. 8). On the basis of the recovered material culture, we dated the site to the Early Iron Age and Antiquity (Кабакчиева 1986, Нехризов 2008).

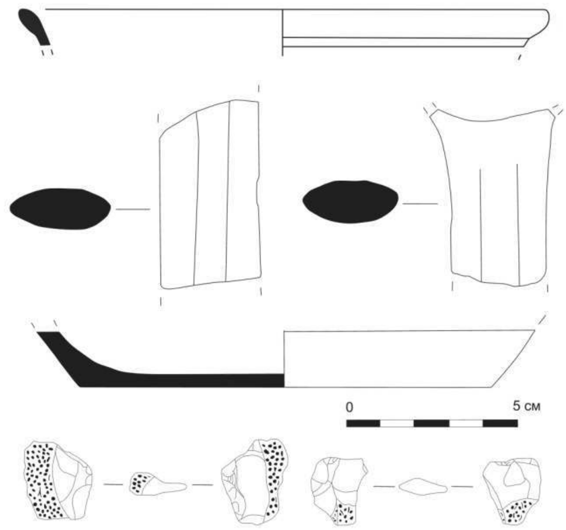


Figure 6 Wheel-made pottery fragments and flint tools.

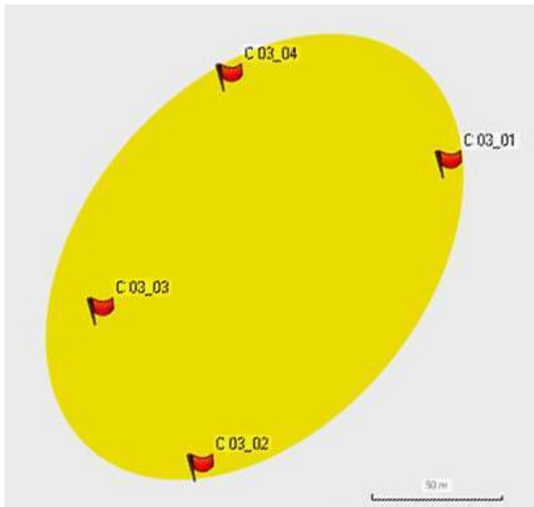


Figure 7 Area of settlement No 3.

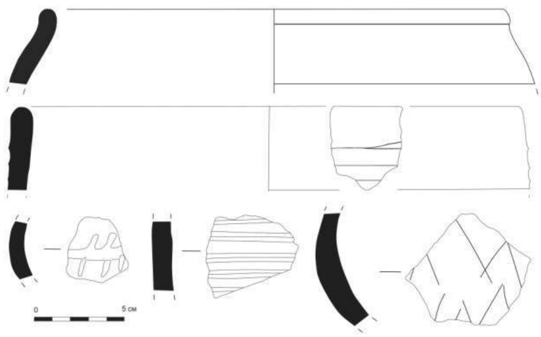


Figure 8 Hand-made pottery fragments.

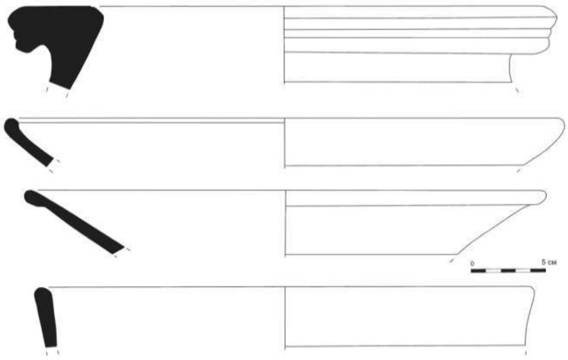


Figure 9 Wheel-made pottery fragments.

Settlement 4 has an area of 19 ha. (Fig. 10). It is situated on the south-west coast of a small river. Two periods of habitation are indicated: Bronze Age and Antiquity. The hand-made pottery material from Bronze Age includes fragments from pots and storage vessels (Fig. 11) (Лещаков 2006). The ceramic material from Antiquity is dominated by fragments from amphorae, pots and plates (Fig. 12) (Кабакчиева 1986).

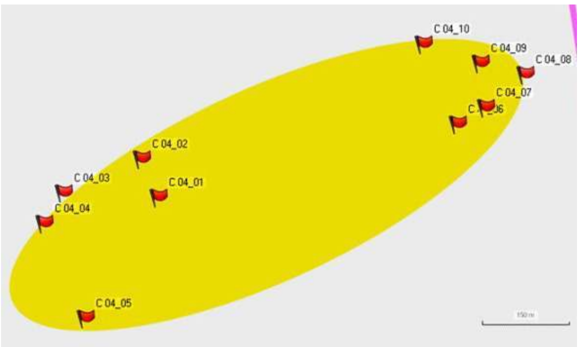


Figure 10 Area of settlement No 4.

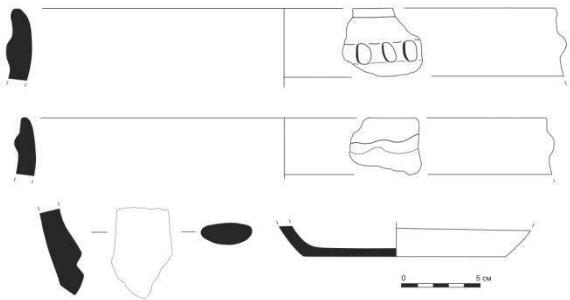


Figure 11 Hand-made pottery fragments.

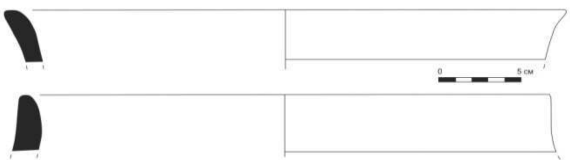


Figure 12 Wheel-made pottery fragments.

Settlement 5 has an area of 0.17 ha (Fig. 13). The team recovered fragments from wheel-made pottery: pots, plates, bowls and amphorae (Fig. 14). They belong to the Antique period (Кабакчиева 1986, Кузманов 1985).

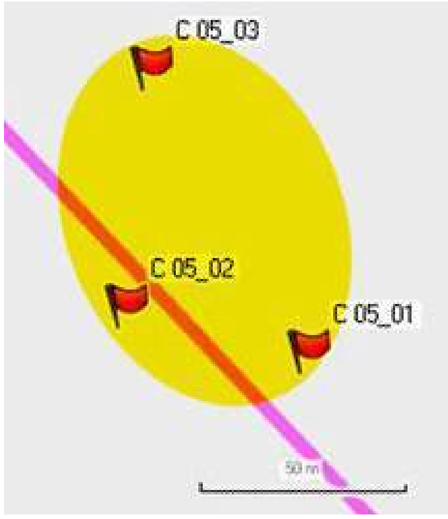


Figure 13 Area of settlement No 5.

Figure 14 Wheel-made pottery fragments.

Settlement 6 has an area of 1.64 ha. (Fig. 15). During the survey hand-made pottery from the Late Bronze Age was located. The decoration of the ceramic assemblage includes incised lines and holes, as well as stamps with circles (Fig. 16) (Лещаков 2006). The open-air settlement was re-inhabited during the Antiquity. The wheel-made pottery from the Antiquity includes pieces from pots, jugs and amphorae (Fig. 17) (Кабакчиева 1986). Analysis of pottery fragments showed that the site presents horizontal stratigraphic variations. In the western part of the site later materials dominated. Flint and stone tools were also retrieved (Fig. 18).

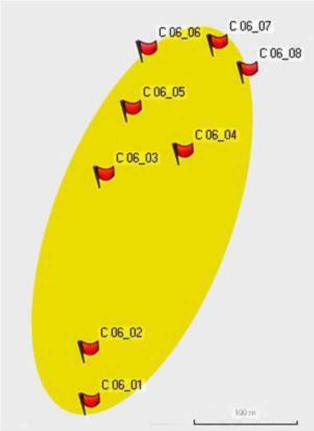


Figure 15 Area of settlement No 6.

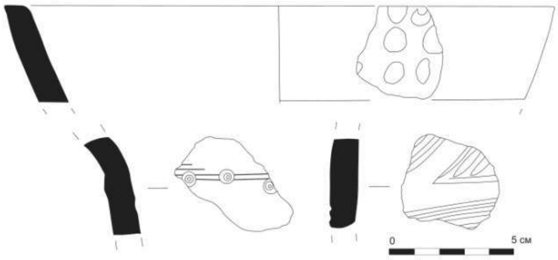


Figure 16 Hand-made pottery fragments.

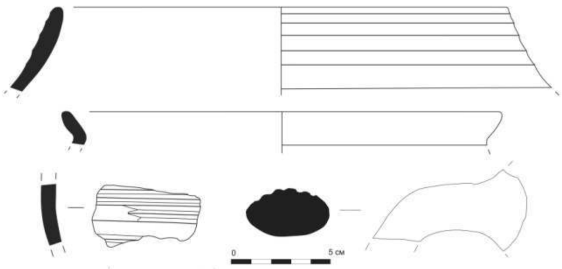


Figure 17 Wheel-made pottery fragments.

Figure 18 Flint and stone tools.

Settlement 7 has an area of 0.7 ha. (Fig. 19). It was inhabited during the Late Antique period (4th-6th centuries AD). During the survey fragments from wheel-made pottery were found: amphorae and storage vessel (Fig. 20) (Кузманов 1985). Some pieces from metal slag were also identified.

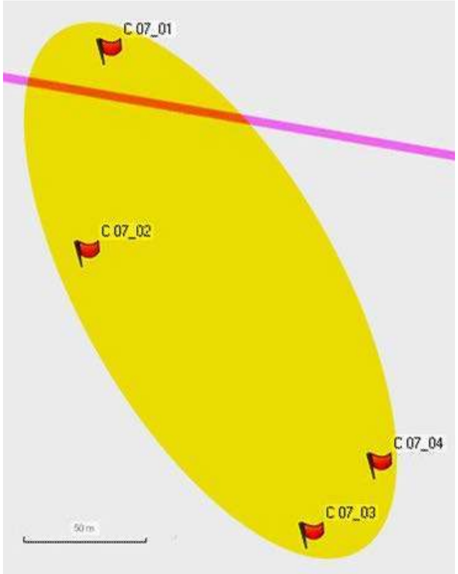


Figure 19 Area of settlement No 7.

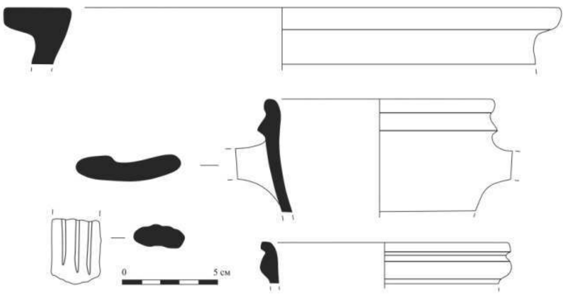


Figure 20 Wheel-made pottery fragments.

Settlement 8 has an area of 6.75 ha. (Fig. 21). It is situated south-east from the lake dam. The survey team collected fragments from hand-made and wheel-made pottery. The ceramic assemblage included: pots, plates, bowls and storage vessels (Fig. 22). Some of them are decorated with channels, incised lines and stamps of circles and lines (Fig. 23). The ceramic materials belong to the Early and Late Iron Ages (Нехризов 2008).

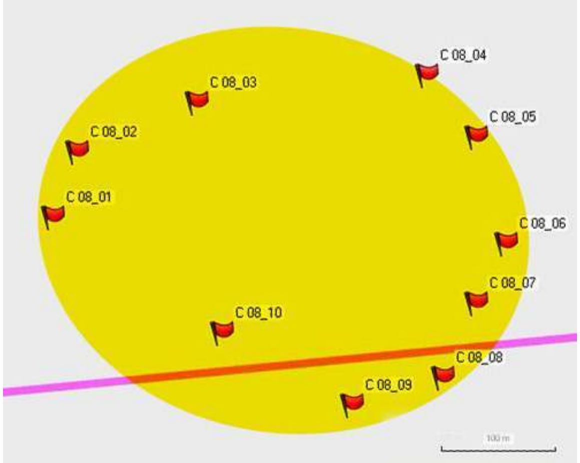


Figure 21 Area of settlement No 8.

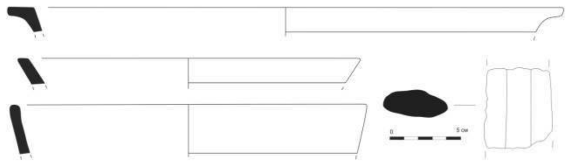


Figure 22 Wheel-made pottery fragments.

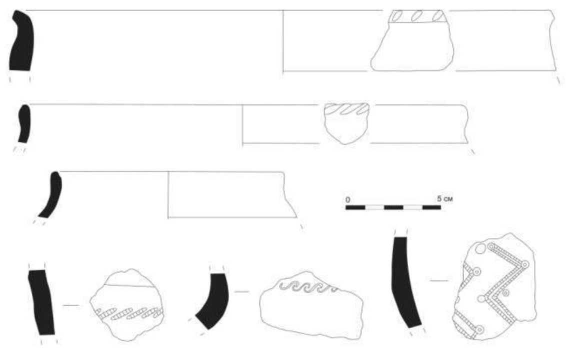


Figure 23 Hand-made pottery fragments.

The monastery "St. George" has an area of 4.64 ha. (Fig. 24). It is situated south-east from Boyadzhik village. A restored temple from the end of 19th c. is situated on site. During the survey, we documented a fortification wall built with small and medium size processed stones and white mortar. Its height is between 1.2 and 1.4 m. and its width is 2.6 m. The wall survives in different spots with the maximum length reaching 12 m. The monastery is situated in the foothill of the Boyadzhik fortress, which is dated to the Late Antique and Medieval periods. The open-air settlement No. 6 was located north-east from the monastery.

Figure 24 Area of the Medieval monastery with modern temple.

The burial mound is small with a height of 0.8 m. and a diameter of 18 m. It is situated on a hill.

Conclusions

The concession Area Boyadzhik provides an example of how geomatics, such as PDAs, GPS systems, and GIS, can help us document the location of ancient open-air settlements more effectively. The experience gained by the archaeologists from the Regional historical museum in Yambol in the use of such technologies places them among the leading teams in field surveying in Bulgaria.

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ΜΕΘΟΔΟΛΟΓΙΑ ΜΟΝΤΕΛΟΠΟΙΗΣΗΣ ΑΝΑΣΚΑΦΙΚΗΣ ΔΙΑΔΙΚΑΣΙΑΣ ΜΕ ΣΩΖΟΜΕΝΑ ΑΡΧΙΤΕΚΤΟΝΙΚΑ ΛΕΙΨΑΝΑ

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Περίληψη/Abstract

Η τεκμηρίωση της ανασκαφής ενός αρχαιολογικού κτηρίου και η διασύνδεση των ποικίλων πληροφοριών (ανασκαφικά ημερολόγια, φωτογραφίες, τοπογραφικά σχέδια, κ.α.) είναι μια διαδικασία πολυσύνθετη που μπορεί να επιτευχθεί μόνο μέσω της εννοιολογικής μοντελοποίησης που αναπαριστά με ορθότητα τη σημασιολογική ερμηνεία τους. Η ανάπτυξη πληροφοριακών συστημάτων που βασίζονται σε σημασιολογικά μοντέλα για τη διαχείριση της αρχαιολογικής πληροφορίας, προσφέρει τεράστιες δυνατότητες αποθήκευσης και ολοκλήρωσης ετερογενών δεδομένων. Στο άρθρο αυτό προτείνεται μια μεθοδολογία μοντελοποίησης των δεδομένων της ανασκαφικής διαδικασίας σε συνδυασμό με σωζόμενα αρχιτεκτονικά λείψανα, με σκοπό τη διευκόλυνση της μελέτης και ανάλυσης της ιστορίας των αρχαιολογικών κτηρίων. Η μεθοδολογία αυτή βασίζεται στο εννοιολογικό μοντέλο αναφοράς CIDOC CRM (διεθνές πρότυπο ISO 21127) και τις επεκτάσεις του (CRMarchaeo, CRMba, CRMinf). Ως παράδειγμα μελέτης για την παρουσίαση του προτεινόμενου μοντέλου αναπαράστασης γνώσης χρησιμοποιήθηκε η Δυτική Οικία του αρχαιολογικού χώρου του Ακρωτηρίου της Θήρας, δεδομένα και ευρήματα της οποίας περιγράφηκαν μέσω των αντίστοιχων στοιχείων του προτεινόμενου μοντέλου.

The documentation of an archaeological building excavation and the integration of diverse information thereon (diaries, photos, topographic plans etc) in a manner that accurately represents their semantic value can be achieved through conceptual modelling. The development of information systems that make use of semantic models for archaeological information management offers huge potential for storing and integrating the heterogeneous datasets generated in this field. This paper presents a model of the connections between excavation procedure data and data on the preserved architectural remains in order to support analysis of the history of buildings known through archaeological contexts. This method works from the Conceptual Reference Model CIDOC CRM (ISO 21127) and key extensions. The West House of the archaeological site of Akrotiri, Thera has been used as a case study for the testing and demonstration of the proposed knowledge model; pertinent archaeological data, finds, and remains were mapped to the proposed model.

Λέξεις Κλειδιά: Εννοιολογική Μοντελοποίηση, CIDOC CRM, Αρχαιολογία, Τεκμηρίωση

Εισαγωγή

Η τεκμηρίωση των ευρημάτων της ανασκαφής μιας αρχαιολογικής θέσης που διασώζει αρχιτεκτονικά λείψανα είναι μια διαδικασία πολύπλοκη και πολύπλευρη. Αυτό οφείλεται κυρίως στην εμπλοκή πολλών ατόμων διαφορετικών ειδικοτήτων και επιστημονικών πεδίων, οι οποίοι με ποικίλους τρόπους και μέσα προσπαθούν να τεκμηριώσουν κάθε δράση ή ενέργεια που συμβαίνει στα πλαίσια της ανασκαφικής διαδικασίας μέσα από ένα ετερογενή και ποικίλο όγκο δεδομένων όπως για παράδειγμα ημερολόγια, αεροφωτογραφίες, τοπογραφικά σχέδια, χάρτες, καταλόγους ευρημάτων, τρισδιάστατες αναπαραστάσεις και άλλα ψηφιακά αντικείμενα. Όλα τα παραπάνω είναι δύσκολο να τεκμηριωθούν εκ των υστέρων χωρίς να χαθούν σημαντικές πληροφορίες. Δεδομένου ότι η ανασκαφή είναι μια καταστρεπτική δραστηριότητα, το αρχείο τεκμηρίωσης ενός αρχαιολογικού κτηρίου πρέπει να περιλαμβάνει όλες τις πληροφορίες που έχουν προκύψει σε όλη τη διάρκεια της ανασκαφής του (Spence 1994).

Η ραγδαία ανάπτυξη των τεχνολογιών της πληροφορικής προσφέρει τεράστιες δυνατότητες συλλογής και αποθήκευσης της πληροφορίας με την ανάπτυξη διαφόρων εργαλείων όπως: βάσεις δεδομένων βασισμένες σε διεθνή πρότυπα (standards) (Midas, Arachne, The Core Data Standard), διάφορα σχήματα μεταδεδομένων (The Dublin Core, Lido) και θησαυροί (The Art & Architecture Thesaurus).

Τα περισσότερα πληροφοριακά συστήματα αρχαιολογικής τεκμηρίωσης σχετίζονται συνήθως με τη διαχείριση και οργάνωση των τομέων μιας ανασκαφής, εξασφαλίζοντας την ταυτοποίηση και ταξινόμηση των ευρημάτων σε όλους τους ανασκαφικούς τομείς. Η μεταγενέστερη μελέτη του υλικού για την τελική δημοσίευση γίνεται συνήθως με διαφορετικά συστήματα και μεθόδους, με αποτέλεσμα να παρουσιάζονται προβλήματα διαλειτουργικότητας, ιδιαίτερα εμφανή στις περιπτώσεις μεγάλων αποθετηρίων γνώσεων όπου απαιτείται η ανταλλαγή των πληροφοριών μεταξύ διαφορετικών συστημάτων. Οι δυσκολίες αυτές οφείλονται κυρίως στην έλλειψη σημασιολογικών δομών οργάνωσης της ανασκαφικής πληροφορίας και των μεταδεδομένων της με βάση διεθνή πρότυπα.

Ανταποκρινόμενη στην ανάγκη αυτή, της σημασιολογικής οργάνωσης των δεδομένων της ανασκαφής ενός αρχαιολογικού κτηρίου, η παρούσα μελέτη αφορά στον καθορισμό μιας μεθοδολογίας εννοιολογικής μοντελοποίησης των δεδομένων της ανασκαφικής διαδικασίας με σωζόμενα αρχιτεκτονικά λείψανα βασιζόμενη σε διεθνή πρότυπα, όπως το CIDOC CRM και τις επεκτάσεις αυτού CRMarchaeo, CRMba και CRMinf. Συγκεκριμένα προτείνεται μια μεθοδολογία εννοιολογικής μοντελοποίησης με σκοπό την παραγωγή ενός εννοιολογικού μοντέλου για τη σημασιολογικά συνεπή τεκμηρίωση της ανασκαφικής διαδικασίας και του παραγόμενου πολύμορφου ανασκαφικού υλικού, το οποίο να διευκολύνει και να παρακολουθεί την δόμηση της επιχειρηματολογίας ως προς την ερμηνεία του παρελθόντος. Η παρουσίαση αυτής της μεθοδολογίας επιχειρείται με τη χρήση των δημοσιευμένων μελετών της ανασκαφής της Δυτικής Οικίας του Ακρωτηρίου της Θήρας. Αποτέλεσμα της μεθοδολογίας αυτής είναι η δημιουργία ενός γενικού μοντέλου αναπαράστασης γνώσης (σχήμα κλάσεων και σχέσεων) (Εικ. 4).

Με την μέθοδο κατασκευής του μοντέλου αυτού, εξασφαλίζεται η σημασιολογική διαλειτουργικότητα των δεδομένων, η συνεπής αναπαράσταση γνώσης για το σύνολο των ανασκαφικών διαδικασιών, η ολοκλήρωση δεδομένων με αρχαιολογικά αντικείμενα, κτήρια και με ερμηνείες που έχουν αποδοθεί ή αποδίδονται, καθώς και η συνεπής αναπαράσταση του παρελθόντος και η σύνδεση με την προέλευση της πληροφορίας. Επίσης, υποστηρίζεται η δυνατότητα επισκόπησης των δεδομένων από πολλαπλές ενότητες ή όψεις όπως για παράδειγμα ανασκαφική, αρχαιολογική/ιστορική, ερμηνευτική και άλλες.

Η αναπαράσταση γνώσης που προτείνεται μπορεί να εφαρμοστεί σε γενικευμένα συστήματα δεδομένων που βασίζονται σε τεχνολογία XML ή και σε δίκτυα γνώσης που βασίζονται σε τεχνολογία αποθετηρίων γράφων, των οποίων τα δεδομένα τους είναι σε μορφή διασυνδεδεμένων δεδομένων RDF.

1. Εννοιολογική μοντελοποίηση - Ανασκαφικά δεδομένα και αρχιτεκτονικά λείψανα

Ανεξάρτητα από τις διάφορες ανασκαφικές μεθόδους ή τις μεθόδους ανάλυσης και ερμηνείας των αρχαιολογικών δεδομένων που χρησιμοποιεί ο κάθε ερευνητής, η παραγωγή λογικών συμπερασμάτων πληροφορίας γνώσης πραγματοποιείται μέσω της ολοκλήρωσης ετερογενών και ποικίλων δεδομένων.

Τα δεδομένα μιας ανασκαφής προέρχονται από γεγονότα παρατήρησης και μετρήσεων των αρχαιολόγων (Banning 2002). Αντίστοιχα, τα σωζόμενα αρχιτεκτονικά λείψανα ενός αρχαιολογικού κτηρίου (τοίχοι, δάπεδα, παράθυρα, κλιμακοστάσια, κ.α.) αποτελούν τα πιο προφανή στοιχεία που μπορεί να αναγνωρίσει ένας αρχαιολόγος κατά την διάρκεια μιας ανασκαφής. Η μελέτη της αρχιτεκτονικής, του τρόπου κατασκευής και των δομικών υλικών τους, παρέχει σημαντικές πληροφορίες για την εξαγωγή συμπερασμάτων σε σχέση με τη δομή και την οργάνωση της κοινωνίας κάθε εποχής. Ειδικά στον τομέα της τεκμηρίωσης του τρόπου κατασκευής των αρχαιολογικών κτηρίων γίνεται ιδιαίτερη μνεία τα τελευταία χρόνια, με απώτερο σκοπό την ανάδειξη και συντήρησή τους (ICOMOS 1990). Στα πλαίσια αυτά έχει αναπτυχθεί ένας ιδιαίτερος κλάδος με το διεθνές όνομα *Building Archaeology* για τη μελέτη όχι μόνο της αρχιτεκτονικής αλλά και γενικότερα του τρόπου κατασκευής αυτών (Schuller 2002).

Στην περίπτωση ειδικά της τεκμηρίωσης των προϊστορικών αρχαιολογικών ανασκαφών, η μοναδικότητα μεταξύ άλλων του αρχαιολογικού περιβάλλοντος, η διασκόρπιση των ευρημάτων και η καταστροφή αυτών από μεταγενέστερες αποθέσεις, καθιστούν δύσκολη και πολύπλοκη την ανασκαφική διαδικασία. Για το λόγο αυτό, ο πρωταρχικός σκοπός της αρχαιολογικής ανασκαφής πρέπει να συμπίπτει με εκείνον της αρχαιολογικής τεκμηρίωσης, δηλαδή την αναπαράσταση του προϊστορικού παρελθόντος και τη σύνδεση (συνδυασμός) όλων των στοιχείων της αρχαιολογικής πληροφορίας (Hadzilakos & Stoumbou 1996).

Η χρήση των οντολογιών και των σημασιολογικών μοντέλων στη σύνδεση όλων των στοιχείων μιας αρχαιολογικής πληροφορίας παίζει πολύ σημαντικό ρόλο γιατί εξασφαλίζει τη συνεπή ολοκλήρωση των δεδομένων κάτω από μια οντολογική ερμηνεία και προσφέρει μια κοινή γλώσσα επικοινωνίας μεταξύ του αρχαιολόγου και του επιστήμονα πληροφορικής (Bekiari *et al*. 2015). Αν λοιπόν η αρχαιολογία είναι μια συναρπαστική αναζήτηση της γνώσης γύρω από τον άνθρωπο και το παρελθόν του (Renfrew & Bahn 2001), τότε η εξαγωγή αυτή της γνώσης μπορεί να επιτευχθεί μέσω των εννοιολογικών μοντέλων και των οντολογιών.

2. Μεθοδολογία - Κατασκευή μοντέλου αναπαράστασης γνώσης

Για να καταστεί εφικτή η ενοποίηση και αλληλοσύνδεση της πολιτισμικής πληροφορίας, απαιτείται ένα ενιαίο πλαίσιο αναφοράς. Η ανάγκη αυτή ώθησε στην δημιουργία του εννοιολογικού μοντέλου αναφοράς **CIDOC CRM** (CIDOC CRM 2017), από τη Διεθνή Επιτροπή Τεκμηρίωσης (CIDOC) του Διεθνούς Συμβουλίου Μνημείων (ICOM). Το εννοιολογικό αυτό μοντέλο αποσκοπεί, στην τεκμηρίωση, ολοκλήρωση, διαμεσολάβηση και ανταλλαγή ετερογενών πηγών δεδομένων πολιτισμικών πληροφοριών, κωδικοποιημένων με διαφορετικά σχήματα μεταδεδομένων (Doerr 2003). Είναι αποτέλεσμα εργασιών τουλάχιστον μιας εικοσαετίας πάνω σε διάφορα εννοιολογικά σχήματα πολιτισμικών βάσεων δεδομένων. Από το 2006 το εννοιολογικό αυτό σχήμα αναφοράς αποτελεί διεθνές πρότυπο (ISO 21127). Το γεγονός αυτό, σε συνδυασμό με την επιτυχή εφαρμογή του προτύπου στον τομέα της αρχαιολογικής τεκμηρίωσης τόσο στην Ελλάδα (Bekiari *et al.* 2015, Κατσιάνης 2012, Tsiafaki & Skoulariki 2008) όσο και διεθνώς (Cripps & May 2010, Doerr *et al.* 2016, Niccolucci *et al.* 2009), καταδεικνύουν ότι το CRM αποτελεί μια καλή βάση για την υποστήριξη μοντελοποίησης της αρχαιολογικής πληροφορίας που μελλοντικά θα έχει όλο και περαιτέρω ζήτηση και διάδοση.

Βασική φιλοσοφία του CIDOC CRM αποτελεί η έννοια του γεγονότος *event modelling* που βασίζεται στην ιδέα ότι η ιστορία ως γεγονός αναπαριστάται από αντικείμενα, ανθρώπους και ιδέες που συναντιούνται στο χώρο και στο χρόνο (Bekiari *et al.* 2008). Η φιλοσοφία αυτή μπορεί να εφαρμοστεί ευρέως για την σημασιολογική μοντελοποίηση μιας αρχαιολογικής ανασκαφής, καθώς τα σημαντικότερα τμήματα αυτής συνδέονται με γεγονότα παρατηρήσεων και ερμηνειών όπως αναλύεται παρακάτω στο παράδειγμα μελέτης της Δυτικής Οικίας του Ακρωτηρίου της Θήρας.

Αποτέλεσμα της χρήσης του CIDOC CRM τα τελευταία χρόνια είναι η δημιουργία συμβατών επεκτάσεων αυτού σε σχέση με πιο εξειδικευμένα πεδία της Πολιτιστικής Κληρονομιάς, οι οποίες συνεχώς εξελίσσονται και εμπλουτίζονται. Ειδικά στον τομέα της αρχαιολογίας, έχουν δημιουργηθεί δυο επεκτάσεις του CIDOC CRM, το **CRMarchaeo** και το **CRMba** (Ronzino 2015). Το πρώτο χρησιμοποιείται για την κωδικοποίηση μεταδεδομένων σχετικά με την ανασκαφική διαδικασία και τις αρχαιολογικές παρατηρήσεις, με τελικό σκοπό την τεκμηρίωση και την ερμηνεία αυτών. Βασίζεται στη σημασία της στρωματογραφικής ακολουθίας, στην οποία βρίσκονται όλα τα χαρακτηριστικά γνωρίσματα ενός αρχαιολογικού χώρου, τα οποία ερευνώνται κατά την διάρκεια μιας αρχαιολογικής ανασκαφής (Harris 1989). Το δεύτερο χρησιμοποιείται για την τεκμηρίωση πληροφοριών σε σχέση με την κατασκευή, χρήση και εξέλιξη των ιστορικών κτηρίων διαμέσου του χρόνου, καθώς και τη μελέτη των δομικών τους στοιχείων, των τοπολογικών σχέσεων και της στρωματογραφίας τους. Η ανάγκη για ολοκλήρωση της πληροφορίας ώθησε την επιστημονική κοινότητα να ξεκινήσει μια προσπάθεια ενοποίησης των επεκτάσεων αυτών, για την τεκμηρίωση κτηριακών κατασκευαστικών δομών που βρίσκονται σε επιχώσεις στρωματογραφικής ακολουθίας (Ronzino 2016). Για την κατασκευή του παρόντος μοντέλου χρησιμοποιήθηκαν επίσης οι επεκτάσεις **CRMgeo** για την τεκμηρίωση της χωρο-χρονικής τοπολογίας και της γεωμετρικής περιγραφής, **CRMsci** για την τεκμηρίωση επιστημονικών παρατηρήσεων και μετρήσεων και **CRMinf** για την τεκμηρίωση συμπερασμάτων και επιχειρημάτων. Οι διάφορες αυτές επεκτάσεις ανανεώνονται συνεχώς με νέες εκδόσεις των μοντέλων, διαθέσιμες στην ηλεκτρονική σελίδα: http://www.cidoc-crm.org/collaborations.

Εικόνα 1 Η σειρά χρήσης του εννοιολογικού μοντέλου CIDOC CRM και των επεκτάσεών του για τη δημιουργία του προτεινόμενου σχήματος μοντελοποίησης.

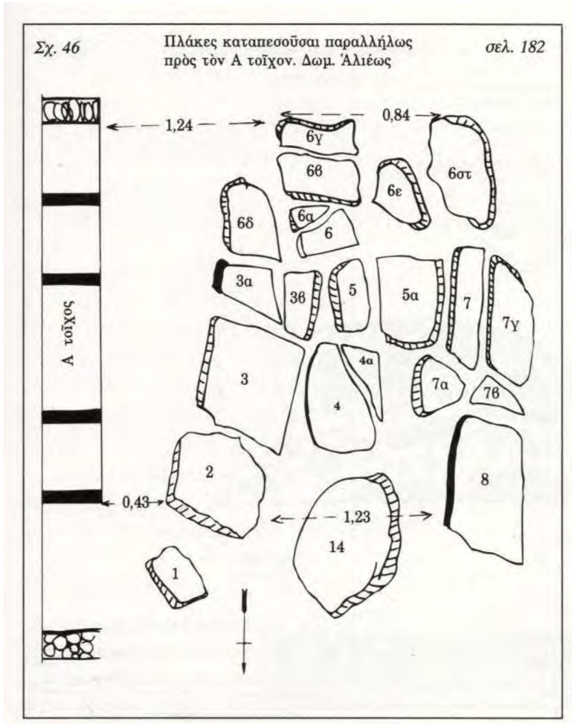
Στην Εικ. 1 παρουσιάζεται η σειρά με την οποία χρησιμοποιήθηκαν τα εννοιολογικά μοντέλα του CIDOC CRM και των επεκτάσεών του για την πραγματοποίηση της παρούσας μοντελοποίησης. Η διαδικασία ξεκινάει από το γενικότερο πλαίσιο, με τη χρήση αρχικά του CIDOC CRM και κατόπιν σταδιακά, με την προσθήκη των συμβατών επεκτάσεών του, για πιο εξειδικευμένη τεκμηρίωση πληροφοριών. Για την παρουσίαση και δοκιμή της προτεινόμενης μοντελοποίησης χρησιμοποιήθηκε το παράδειγμα της Δυτικής Οικίας του αρχαιολογικού χώρου του Ακρωτηρίου της Θήρας, δεδομένα και ευρήματα της οποίας περιγράφηκαν μέσω των αντίστοιχων στοιχείων του προτεινόμενου μοντέλου, όπως αναλύεται παρακάτω. Η βασική ιδέα προκύπτει από το συνδυασμό των ανασκαφικών δεδομένων με τα σωζόμενα αρχιτεκτονικά λείψανα που προέρχονται από: α) γεγονότα παρατήρησης που συνδέονται με τις πληροφορίες από την ανασκαφική διαδικασία και συμβάλουν καθοριστικά στην ανασύνθεση του παρελθόντος και β) γεγονότα απόδοσης ερμηνείας που προκύπτουν από τα διάφορα υποθετικά συμπεράσματα μέσα από τη διαδικασία μελέτης και ανάλυσης των παραπάνω δεδομένων και εξαρτώνται σε μεγάλο βαθμό από το επιστημονικό και πολιτιστικό υπόβαθρο των αρμόδιων αρχαιολόγων.

3. Περίπτωση μελέτης - Δυτική Οικία Θήρας - Δωμάτιο 5

Ως παράδειγμα μελέτης για την παρουσίαση της προτεινόμενης μοντελοποίησης όπως αναφέρθηκε παραπάνω, χρησιμοποιήθηκε η Δυτική Οικία του προϊστορικού οικισμού του Ακρωτηρίου της Θήρας. Το παράδειγμα του συγκεκριμένου αρχαιολογικού κτηρίου επιλέχτηκε κυρίως λόγω της άριστης κατάστασης διατήρησης πληθώρας σωζόμενων αρχιτεκτονικών λειψάνων που μπορούν να συνδυαστούν με τα ανασκαφικά δεδομένα, καθώς και της ύπαρξης αρκετών σημαντικών δημοσιευμένων μελετών σε σχέση με την αρχιτεκτονική και κατασκευή του που προσφέρουν τεκμηριωμένα συμπεράσματα.

Εικόνα 2 Δυτική Οικία, Δωμάτιο 5. Σωζόμενο τμήμα πλακόστρωτου δαπέδου στον άνω όροφο. Στο βάθος η τοιχογραφία του Ψαρά όπως βρέθηκε κατά την διάρκεια της ανασκαφής (Μαρινάτος 1974, πίν. 38β).

Γεγονότα παρατήρησης: η αποκάλυψη της Δυτικής Οικίας πραγματοποιήθηκε από τον Σπ. Μαρινάτο τα πρώτα χρόνια της ανασκαφής (1967-1973) του οικισμού του Ακρωτηρίου της Θήρας. Πρόκειται για ένα κτήριο αυτοτελές, χαρακτηριστικό παράδειγμα των οικιών του οικισμού του Ακρωτηρίου. Βρίσκεται στο κέντρο του δυτικού τμήματος του οικισμού όπου και οφείλει το όνομά του. Καλύπτει μια περιοχή στο ισόγειο 147 τ.μ. Εκτός από το ισόγειο, σώζει τον πρώτο όροφο και πιθανότατα και δεύτερο όροφο στο Δωμάτιο 6. Αποτελείται από δεκαέξι συνολικά δωμάτια, οκτώ στο ισόγειο, επτά στον πρώτο όροφο και ένα στον δεύτερο όροφο. Διαθέτει δυο κλιμακοστάσια για την επικοινωνία ανάμεσα στους ορόφους και μια είσοδο στη νοτιοανατολική (ΝΑ) του γωνία (Palyvou 2005). Πρόκειται για οικοδόμημα της προηγούμενης περιόδου που επισκευάστηκε μετά από σεισμό, στα μέσα του 17^{ου} αι. π.Χ. (Ντούμας 2016). Το Δωμάτιο 5 που εξετάζεται, βρίσκεται στη βορειοδυτική (ΒΔ) γωνία της Δυτικής Οικίας, είναι τετράγωνο στην κάτοψη και έχει διαστάσεις 4 x 4 μ. Ονομάστηκε συμβατικά από τον Μαρινάτο «Δωμάτιον Αλιέως» λόγω των πολυτελέστατων τοιχογραφιών που βρέθηκαν στον πρώτο όροφο με παραστάσεις ψαράδων που κοσμούσαν τις εσωτερικές επιφάνειες των συμπαγών τοίχων του δωματίου. Κατά μήκος του βόρειου και δυτικού τοίχου του Δωματίου 5 στον πρώτο όροφο, σώζεται κατά χώρα, σειρά σχιστολιθικών πλακών του δαπέδου (Μαρινάτος 1974) (Εικ. 2). Αντίστοιχα, στην επίχωση του ισογείου του ίδιου δωματίου βρέθηκαν αρκετές πεσμένες πλάκες (Εικ. 3), οι περισσότερες σχεδόν κατακόρυφα, κατά μήκος του ανατολικού, του βόρειου και του δυτικού τοίχου (Μιχαηλίδου 2001). Εκτός από το σωζόμενο τμήμα του πλακόστρωτου δαπέδου, στον άνω όροφο του Δωματίου 5 είναι ορατά επίσης σήμερα σωζόμενα αρχιτεκτονικά λείψανα των εξωτερικών τοίχων οι οποίοι αναστηλώθηκαν τμηματικά, καθώς και των κατωφλιών των πολυπαραθύρων.



Εικόνα 3 Δυτική Οικία, Δωμάτιο 5. Σχέδιο ανασκαφικού ημερολογίου Ν. Γκιολέ των πλακών του δαπέδου του ορόφου που βρέθηκαν πεσμένες κατά μήκος του ανατολικού τοίχου (Μιχαηλίδου 2001, εικ. 29).

Γεγονότα ερμηνείας: Σύμφωνα με τον ανασκαφέα το Δωμάτιο 5 στον πρώτο όροφο είναι πολυτελούς χρήσης, με οκτώ παράθυρα (Μαρινάτος 1974), το οποίο φαίνεται να λειτουργούσε ως στεγασμένη βεράντα (Ντούμας 2016). Η σειρά σχιστολιθικών πλακών που σώζεται στη βορειοδυτική (ΒΔ) γωνία του αποτελεί τμήμα του πλακόστρωτου δαπέδου που στηριζόταν στον αναβαθμό των εξωτερικών τοίχων, με κόκκινο κονίαμα στους αρμούς των πλακών. Αντίστοιχα, οι πλάκες που βρέθηκαν στην επίχωση του ισογείου αποτελούν πεσμένα τμήματα του αρχικού δαπέδου του άνω ορόφου που πριν την καταστροφή, ήταν όλο πλακόστρωτο. Συγκεκριμένα "οι πλάκες που έπεσαν παράλληλα προς τον ανατολικό τοίχο αρχίζουν από το χώρο μπροστά στην βόρεια θύρα και φτάνουν μέχρι και το τελευταίο ερμάριο. Αρχίζουν από βάθος 0,34 μ. από την αρχική θέση του δαπέδου και ξεπερνούν τα 2,50 μ. μέσα στην επίχωση του ισογείου" (Μιχαηλίδου 2001).

4. Παρουσίαση Μοντέλου Αναπαράστασης Γνώσης: Το παράδειγμα της Δυτικής Οικίας.

Η παρουσίαση του προτεινόμενου μοντέλου γίνεται με την περιγραφή των παραπάνω δεδομένων της Δυτικής Οικίας μέσω των αντίστοιχων στοιχείων του (Εικ. 4), σε τέσσερις ενότητες: α. Αρχαιολογική Ανασκαφή, β. Ανασκαφική Διαδικασία, γ. Σωζόμενα (και μη) Αρχιτεκτονικά Λείψανα και δ. Επιχειρηματολογία. Σε τμήμα της εικόνας του μοντέλου αποτυπώνονται με διαφορετικά χρώματα οι κλάσεις και οι ιδιότητες σε σχέση με το CIDOC CRM και τις διάφορες επεκτάσεις αυτού που χρησιμοποιήθηκαν.

4.α Αρχαιολογική Ανασκαφή

Η πρώτη ενότητα του μοντέλου (Εικ. 4) περιγράφει τα δεδομένα που ορίζουν την ταυτότητα μιας αρχαιολογικής ανασκαφής, αφού αυτή διατηρεί τον κεντρικό ρόλο στην εργασία πεδίου, καθώς αποδίδει τις πιο αξιόπιστες πληροφορίες για τις ανθρώπινες δραστηριότητες του παρελθόντος. Οι σύγχρονες δραστηριότητες λαμβάνουν χώρα οριζοντίως στο χώρο, ενώ οι μεταβολές σε αυτές τις δραστηριότητες συμβαίνουν κάθετα στο πέρασμα του χρόνου (Renfrew & Bahn 2001).

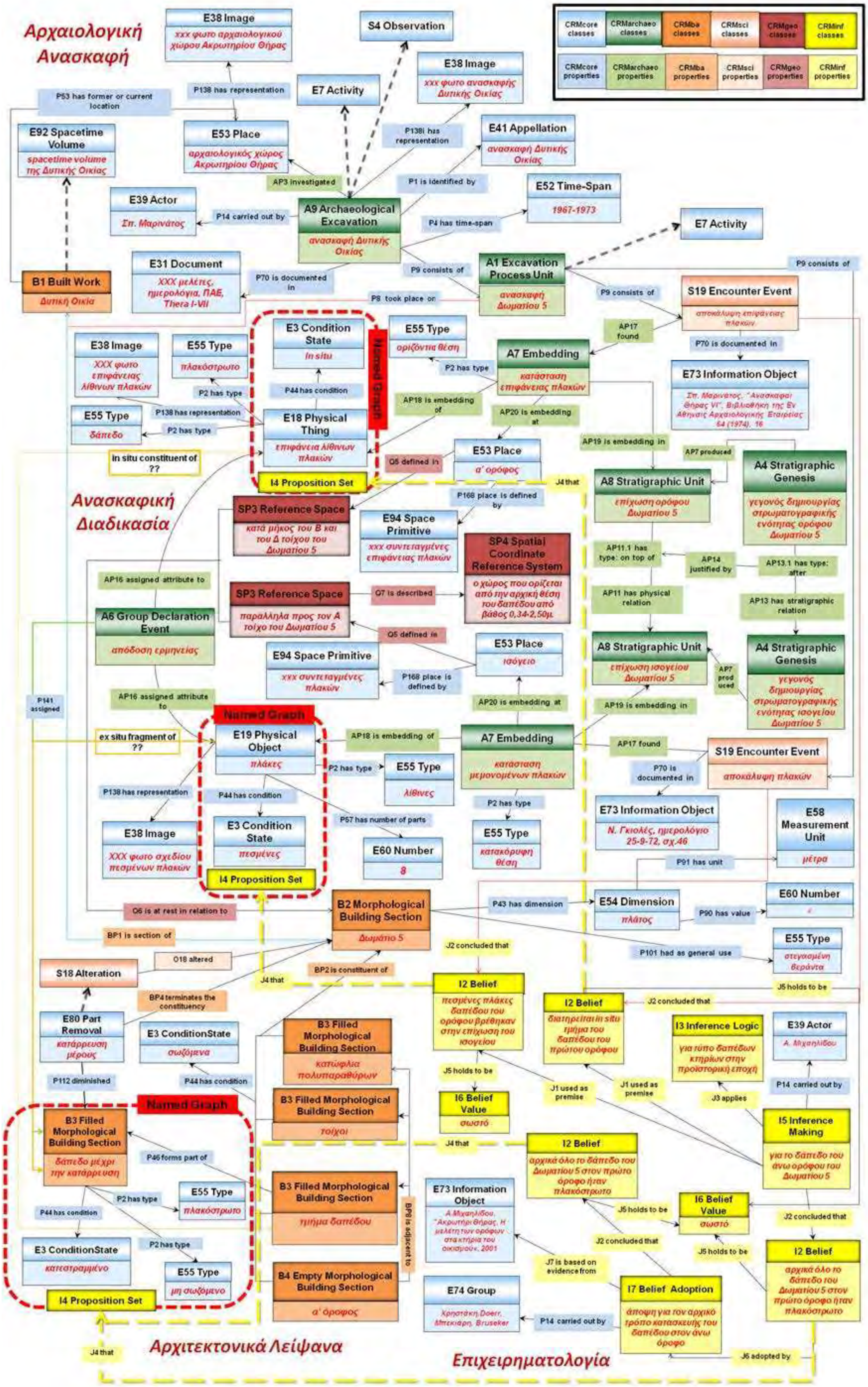
Η έννοια αυτή μοντελοποιείται με την οντότητα *A9 Archaeological Excavation*. Η οντότητα αυτή, αφορά στο γενικότερο πλαίσιο των δραστηριοτήτων που διεξάγονται σε μια συγκεκριμένη περιοχή (αρχαιολογικός χώρος) *E53 Place,* από ένα άτομο (ανασκαφέας) *E39 Actor* που είναι ο επιστημονικά υπεύθυνος για τη διεξαγωγή των επιμέρους ανασκαφικών διαδικασιών και για την τεκμηρίωση της συνολικής διαδικασίας. Η οντότητα αυτή είναι υποκλάση της παρατήρησης *S4 Observation* και της δραστηριότητας *E7 Activity,* η οποία μοντελοποιεί μια ανθρώπινη δραστηριότητα που διεξάγεται σε ένα χρονικό διάστημα *E52 Time-Span*. Τα ανασκαφικά έγγραφα και οι διάφορες μελέτες *E31 Document* είναι προϊόντα ενεργειών και δραστηριοτήτων που συμβαίνουν και αποσκοπούν στην τεκμηρίωσή της. Ο αρχαιολογικός χώρος *E53 Place* ορίζεται ως η τοποθεσία που περιλαμβάνει φυσικά κατάλοιπα που μαρτυρούν ανθρώπινη δραστηριότητα του παρελθόντος (Burke & Smith 2004) και τεκμηριώνεται μεταξύ άλλων από σχέδια και φωτογραφίες *E38 Image* που αποτελούν το ανασκαφικό του αρχείο.

Κάθε αρχαιολογική ανασκαφή αποτελείται από διάφορες ανασκαφικές διαδικασίες *A1 Excavation Process Unit* που τεκμηριώνουν τις ενέργειες αφαίρεσης υλικού και καταγραφής κάτω από συγκεκριμένους κανόνες και σε προκαθορισμένο χώρο. Ανάλογα με τη μεθοδολογία και τους κανόνες κάθε ανασκαφής, η ενότητα της ανασκαφικής διαδικασίας μπορεί να περιγράφει την ανασκαφή ενός δωματίου, μιας αρχιτεκτονικής κατασκευής, ενός τοίχου και άλλων μονάδων. Η ανασκαφική διαδικασία λαμβάνει χώρα σε ένα αρχαιολογικό κτήριο *B1 Built Work* το οποίο είναι υποκλάση της οντότητας *E92 Space-time* υποδηλώνοντας έτσι την χωρο-χρονική ύπαρξη του κτηρίου, από τη στιγμή της κατασκευής του μέχρι σήμερα. Η διαχρονικότητα αυτή του αρχαιολογικού κτηρίου ορίζεται ως οι διάφορες δραστηριότητες και διαδικασίες που συμβαίνουν διαμέσου του χρόνου και σε ένα συγκεκριμένο χώρο (Gamble 2001). Οι έννοιες του χώρου και του χρόνου αποτελούν τα πιο σημαντικά στοιχεία για την επίτευξη σημασιολογικής διαλειτουργικότητας.

4.β Ανασκαφική Διαδικασία

Στη δεύτερη ενότητα του μοντέλου (Εικ. 4) τεκμηριώνονται τα διάφορα γεγονότα παρατήρησης που συνδέονται με την ανασκαφική διαδικασία.

Γεγονότα αποκάλυψης αντικειμένων (*S19 Encounter Event*)**:** κάθε ενότητα ανασκαφικής διαδικασίας *A1 Excavation Process Unit* περιλαμβάνει *P9 consists of* διάφορα γεγονότα αποκάλυψης αντικειμένων *S19 Encounter Event* (Doerr *et. al* 2016). Τα γεγονότα αυτά είναι αποτέλεσμα παρατήρησης η οποία παράγει γνώση σε σχέση με το αντικείμενο προς τεκμηρίωση και ειδικότερα τον χώρο που αυτό βρέθηκε. Το κάθε γεγονός αποκάλυψης αντικειμένων τεκμηριώνεται *AP17 found* από την κατάσταση αποκάλυψής του *A7 Embedding,* καθώς και το έγγραφο ή την πηγή τεκμηρίωσής του *E73 Information Object.*



Εικόνα 4 Ολοκληρωμένο παράδειγμα του μοντέλου αναπαράστασης γνώσης: Η περίπτωση μελέτης της Δυτικής Οικίας.

Κατάσταση αντικειμένων (*A7 Embedding)*: τα αρχιτεκτονικά λείψανα των αρχαιολογικών κτηρίων δεν μπορούν να ερμηνευθούν μεμονωμένα αν δεν ληφθούν υπόψη τα δεδομένα του περιβάλλοντος στο οποίο βρέθηκαν. Για το λόγο αυτό, μια από τις βασικές πληροφορίες που πρέπει να περιλαμβάνει ένα αρχείο σε σχέση με τη μελέτη των αρχαιολογικών κτηρίων είναι αφενός, η θέση των αντικειμένων στο στρωματογραφικό τους περιβάλλον και αφετέρου, η θέση τους σε σχέση με άλλα τμήματα του κτηρίου (Spence 1994). Το στρωματογραφικό περιβάλλον των αντικειμένων προς τεκμηρίωση και η σχετική τους θέση μέσα σε αυτό, σε συνδυασμό με την απόλυτη θέση τους και το χρόνο διεξαγωγής της παρατήρησης, μπορούν να συμβάλουν στην εξαγωγή συμπερασμάτων για την ιστορία τους. Η δυνατότητα αυτή δίνεται μέσω της μοντελοποίησης της κατάστασης *A7 Embedding* των αντικειμένων αυτών, σε σχέση με το γεγονός αποκάλυψής τους *S19 Encounter Event*. Η κατάσταση αυτή έχει συγκεκριμένο τύπο *E55 Type* και συνδέεται με τρεις βασικές έννοιες: α) την **τοποθεσία** *E53 Place* όπου μοντελοποιείται η σχετική και απόλυτη θέση των αντικειμένων (A7 Embedding: AP20 is embedding at: E53 Place), β) τη **στρωματογραφική ενότητα** *A8 Stratigraphic Unit* όπου μοντελοποιείται η ομάδα στρωμάτων ή το στρώμα όπου βρέθηκε το αντικείμενο (A7 Embedding: AP19 is embedding in: A8 Stratigraphic Unit) και γ) τα ίδια τα **αντικείμενα** *E18 Physical Thing, E19 Physical Object (*A7 Embedding: AP18 is embedding of: E18 Physical Thing ή E19 Physical Object). Η ταυτότητα των αντικειμένων αυτών ορίζεται από τα διάφορα χαρακτηριστικά τους όπως για παράδειγμα τον τύπο τους *E55 Type*, την ανασκαφική τους φωτογραφία ή το ανασκαφικό τους σχέδιο *E38 Image*, την κατάσταση διατήρησής τους *E3 Condition State* και το πλήθος τους *E60 Number*.

Τεκμηρίωση τοποθεσίας *(E53 Place)*: μια από τις βασικές μεθόδους τεκμηρίωσης της θέσης εύρεσης των αντικειμένων είναι η καταγραφή των τριών διαστάσεών τους σε σχέση με ένα σταθερό σημείο, όπως για παράδειγμα το επίπεδο της θάλασσας. Με τον τρόπο αυτό ορίζεται η θέση του αντικειμένου στο χώρο (Harris 1989). Εκτός από τη σχετική θέση των αντικειμένων υπάρχει και η απόλυτη θέση αυτών με την περιγραφή των γεωγραφικών τους συντεταγμένων. Με την βοήθεια του CRMgeo η σχετική θέση *SP3 Reference Space* των αντικειμένων τεκμηριώνεται αναφορικά με τα σωζόμενα αρχιτεκτονικά στοιχεία *B2 Morphological Building Section*, καθώς και με το ανασκαφικό τους βάθος *SP4 Spatial Coordinate Reference System*. Με τον τρόπο αυτό πραγματοποιείται η σύνδεση των ανασκαφικών δεδομένων με τα σωζόμενα αρχιτεκτονικά λείψανα. Η απόλυτη θέση των αντικειμένων τεκμηριώνεται με την περιγραφή των γεωγραφικών συντεταγμένων τους *E94 Space Primitive*.

Τεκμηρίωση στρωματογραφικής ακολουθίας: η στρωματογραφία ορίζεται ως η μελέτη και η επαλήθευση του σχηματισμού των στρωμάτων - η ανάλυση στην κάθετη, χρονική διάσταση μιας σειράς στρωμάτων, στην οριζόντια χρονική διάσταση του χώρου (παρόλο που στην πράξη συνήθως λίγα στρώματα είναι επακριβώς οριζόντια) (Renfrew & Bahn 2001). Πρωταρχικός στόχος της μελέτης της αρχαιολογικής στρωματογραφίας πρέπει να είναι η τεκμηρίωση της σχετικής ακολουθίας των στρωματογραφικών ενοτήτων *A8 Stratigraphic Unit*, των στρωμάτων και των χαρακτηριστικών τους. Με τον τρόπο αυτό, τεκμηριώνεται παράλληλα η χωρο-χρονική τοποθέτηση των αντικειμένων σε μια ακολουθία σχετικής χρονολόγησης σε σχέση με το στρώμα ή τη στρωματογραφική ενότητα όπου βρέθηκαν. Η στρωματογραφική ακολουθία επεξηγεί τον τρόπο σχηματισμού των αρχαιολογικών χώρων (Harris 1989). Με τη χρήση του CRMarchaeo, η τεκμηρίωση της ακολουθίας ανάμεσα σε δυο στρωματογραφικές ενότητες *A8 Stratigraphic Unit* όπου βρέθηκαν τα αντικείμενα τη στιγμή της αποκάλυψής τους, πραγματοποιείται με τη μοντελοποίηση της φυσικής τους σχέσης (υποδήλωση χώρου) *AP11 has physical relation.* Αντίστοιχα τεκμηριώνεται και η στρωματογραφική σχέση (υποδήλωση χρόνου) *AP13 has stratigraphic relation* μεταξύ των γεγονότων της δημιουργίας των στρωματογραφικών ενοτήτων *A4 Stratigraphic Genesis: AP7 produced: A8 Stratigraphic Unit.* Στην περίπτωση της μελέτης του Δωματίου 5 της Θήρας, ο τύπος της φυσικής σχέσης ανάμεσα στην στρωματογραφική ενότητα του ορόφου και εκείνη του ισογείου είναι *AP11.1 has type: on top of.* Αντίστοιχα, ο τύπος της στρωματογραφικής σχέσης μοντελοποιείται ως *AP13.1 has type: after*. Ο τύπος των στρωματογραφικών σχέσεων δικαιολογείται από τον τύπο των φυσικών σχέσεων (AP13.1 has type: after: AP14 justified by: AP11.1 has type: on top of). Οι τύποι των σχέσεων *has type* προκύπτουν από την μοντελοποίηση του γεγονότος δημιουργίας της στρωματογραφίας *A4 Stratigraphic Genesis*.

4.γ Σωζόμενα αρχιτεκτονικά λείψανα και σύνδεση με ανασκαφικά δεδομένα

Στην τρίτη ενότητα του μοντέλου (Εικ. 4) τεκμηριώνονται τα δεδομένα που σχετίζονται με τα αρχιτεκτονικά λείψανα του κτηρίου της Δυτικής Οικίας και αποτελούν επίσης αντικείμενα παρατήρησης. Στη συνέχεια, γίνεται σύνδεση αυτών με τα ανασκαφικά δεδομένα μέσω του γεγονότος απόδοσης ερμηνείας αναφορικά με την αρχική κατασκευή του κτηρίου, δηλαδή τον τρόπο κατασκευής του Δωματίου 5 στον άνω όροφο και τέλος προτείνονται δύο νέες ιδιότητες.

Τμήματα κτηρίου: *(B2 Morphological Building Section):* κάθε αρχαιολογικό κτήριο *B1 Built Work,* όπως αυτό περιγράφηκε στην ενότητα 4.α, αποτελείται από διάφορα λειτουργικά τμήματα *B2 Morphological Building Section*. Τα τμήματα αυτά, ανάλογα με τις ανάγκες κάθε τεκμηρίωσης, έχουν διάφορα χαρακτηριστικά που ορίζουν την ταυτότητά τους, όπως για παράδειγμα οι διαστάσεις τους *E54 Dimension* και η χρήση τους *E55 Type*.

Σωζόμενα λείψανα τμημάτων κτηρίου *(B3 Filled Morphological Building Section, B4 Empty Morphological Building Section).* Στις ανασκαφές αρχαιολογικών κτηρίων ιδιαίτερο ενδιαφέρον παρουσιάζουν τα αρχιτεκτονικά τμήματα που βρέθηκαν στη θέση τους σε σχέση με την αρχική κατασκευή, δηλαδή *in situ*. Στο σχήμα μοντελοποιείται η κατάσταση διατήρησής τους *E3 Condition State* και η σχέση τους με το τμήμα του κτηρίου στο οποίο ανήκουν, δομικά *BP2 is constituted by* και τοπολογικά *BP8 is adjacent to.*

Γεγονός κατάρρευσης *(S18 Alteration)*: για την αναπαράσταση της αρχικής μορφής των διαφόρων τμημάτων του κτηρίου με σκοπό την ανασύνθεση του παρελθόντος, την απόδοση ερμηνείας στα υπό τεκμηρίωση αντικείμενα και τη σύνδεση των ανασκαφικών δεδομένων με τα σωζόμενα λείψανα, μοντελοποιείται το γεγονός της κατάρρευσης του Δωματίου 5. Η μοντελοποίηση του γεγονότος αυτού *S18 Alteration: O18 altered: B2 Morphological Building Section* συνδέει χρονικά το παρόν με το παρελθόν, δηλαδή τα αρχιτεκτονικά λείψανα που είναι ορατά σήμερα με τμήμα αυτών πριν την καταστροφή *B3 Filled Morphological Building Section,* το οποίο δεν σώζεται σήμερα *E3 Condition State.*

Γεγονός απόδοσης ερμηνείας: η σύνδεση των ανασκαφικών δεδομένων με τα σωζόμενα (και μη) αρχιτεκτονικά λείψανα γίνεται επίσης μέσω του γεγονότος απόδοσης ερμηνείας. Συγκεκριμένα, χρησιμοποιείται η κλάση *A6 Group Declaration Event* που περιγράφει τις ενέργειες που έχουν σαν αποτέλεσμα την αναγνώριση και την απόδοση ερμηνείας *AP18 assigned attribute to* σε δύο ή περισσότερα φυσικά αντικείμενα *E18 Physical Thing/E19 Physical Object* όπως αυτά αποκαλύφθηκαν κατά την ανασκαφή, ως μέρη του αρχικού μη σωζόμενου αρχιτεκτονικού τμήματος *B3 Filled Morphological Building Section,* όπως αυτό μοντελοποιήθηκε μέσω του γεγονότος κατάρρευσης. Στην περίπτωση της Δυτικής Οικίας η απόδοση ερμηνείας αφορά στις πεσμένες πλάκες της επίχωσης του ισογείου του Δωματίου 5 και στο σωζόμενο τμήμα του δαπέδου του άνω ορόφου, ως τμήματα του αρχικού δαπέδου στον άνω όροφο.

Προτεινόμενες ιδιότητες: Στο σημείο αυτό προτείνονται ενδεικτικά δύο νέες ιδιότητες στο μοντέλο που αποτελούν τμήματα ενός ευρύτερου μονοπατιού σχέσεων και κλάσεων που πρέπει να διερευνηθεί. Ονομάζονται *in situ constituent of* και *ex situ fragment of.* Οι ιδιότητες αυτές είναι απαραίτητες για την εξαγωγή συμπερασμάτων σε σχέση με την ιστορία των αντικειμένων διαμέσου του χρόνου και του χώρου. Αποτελούν προϊόντα παρατήρησης της κατάστασης των αντικειμένων για το αν βρέθηκαν στη αρχική τους θέση τη στιγμή της αποκάλυψής τους σε σχέση με την αρχική φάση του κτηρίου (*production event)* και για ένα συγκεκριμένο χρονικό διάστημα.

4.δ Επιχειρηματολογία

Στην τελευταία ενότητα (Εικ. 4) μοντελοποιείται με τη βοήθεια του CRMinf η επιχειρηματολογία σχετικά με τον τρόπο κατασκευής του αρχαιολογικού κτηρίου.

Για τη δημιουργία γενικότερα υποθετικών συμπερασμάτων διακρίνονται τρεις βασικές πηγές γνώσης: α) η παρατήρηση *Observation* με την έννοια της φυσικής επιστήμης ως ανθρώπινη δραστηριότητα, β) οι διάφορες δημοσιευμένες απόψεις *Belief Adoption* και γ) ένα άλλο συμπέρασμα *Inference Making*. Οι παραπάνω πηγές γνώσης είναι τύποι της επιχειρηματολογίας *Argumentation*, η οποία γενικότερα ερμηνεύεται ως η διαδικασία που επιβεβαιώνει, δημιουργεί ή αλλάζει ένα υποθετικό συμπέρασμα. Για την αποδοχή ή μη ενός επιχειρήματος απαιτείται ένα δεύτερο επιχείρημα που μπορεί να αξιολογήσει την ορθότητα του πρώτου και ενδεχομένως να προσθέσει νέες πηγές γνώσης. Αυτό πραγματοποιείται με την τυπικά δομημένη αναπαράσταση (μοντελοποίηση) όλων των επιχειρημάτων και την αξιολόγηση της εγκυρότητας του περιεχομένου τους σε οποιαδήποτε χρονική στιγμή (Doerr *et al.* 2011).

Στο παράδειγμα (Εικ. 4) παρουσιάζεται η μοντελοποίηση της επιχειρηματολογίας σχετικά με το δάπεδο του άνω ορόφου του Δωματίου 5 της Δυτικής Οικίας *I5 Inference Making.* Η συμπερασματική άποψη *I2 Belief* της Μιχαηλίδου *E39 Actor ότι "αρχικά όλο το δάπεδο του δωματίου στον πρώτο όροφο ήταν πλακόστρωτο"* (Μιχαηλίδου 2001) προκύπτει από τις απόψεις *I2 Belief* των ανασκαφέων όπως περιγράφηκαν στην παρούσα μοντελοποίηση και συγκεκριμένα ότι: α) πεσμένες πλάκες του δαπέδου του ορόφου βρέθηκαν στην επίχωση του ισογείου και β) διατηρείται στη θέση του τμήμα του δαπέδου του πρώτου ορόφου. Οι απόψεις αυτές των ανασκαφέων προέρχονται απευθείας από *Observation Events* (S19 Encounter Event: J2 concluded that: I2 Belief) και αξιολογούνται *I6 Belief Value* με βάση την ορθότητα του περιεχομένου τους, δηλαδή τα δεδομένα από τα οποία προέρχονται *I4 Proposition Set*. Με τον τρόπο αυτό επιτυγχάνεται η παρακολούθηση της προέλευσης της επιχειρηματολογίας.

Για τη διευκόλυνση της επιχειρηματολογίας και την κριτική (αξιολόγηση) του παραπάνω επιχειρήματος, μοντελοποιείται ένα δεύτερο επιχείρημα σχετικά με την άποψη για τον τρόπο κατασκευής του δαπέδου *I7 Belief Adoption*, από διαφορετικούς μελετητές (τη συντακτική ομάδα της παρούσας μελέτης) *E74 Group* που καταλήγει σε μια άλλη άποψη *I2 Belief* με το ίδιο περιεχόμενο. Η αξιολόγηση του περιεχομένου της άποψης αυτής βασίζεται σε ένα πληροφοριακό αντικείμενο (τεκμήριο) *E73 Information Object.*

Η σημασιολογική μοντελοποίηση της σύνδεσης των δεδομένων προέλευσης *I4 Proposition Set* με τις διάφορες απόψεις *I2 Belief* της επιχειρηματολογίας, μπορεί να γίνει υπό την μορφή ενός *Named Graph* (Carroll *et al.*). Η δομή αυτή αναπαράστασης γνώσης δίνει τη δυνατότητα χωρίς περιορισμούς, ομαδοποίησης των παραπάνω δεδομένων που αποκτούν πλέον μια ξεχωριστή ταυτότητα (URI) και λειτουργούν ως ξεχωριστή οντότητα με όλες τις ιδιότητες, τα χαρακτηριστικά και τις σχέσεις που μπορεί αυτή να έχει. Στο προτεινόμενο παράδειγμα μοντελοποίησης (Εικ. 4) απεικονίζονται τρία *Named Graphs* σε ξεχωριστό πλαίσιο, σε σχέση με τις τέσσερις απόψεις *I2 Belief* της επιχειρηματολογίας για τον τρόπο κατασκευής του δαπέδου του άνω ορόφου του Δωματίου 5 της Δυτικής Οικίας.

Συμπεράσματα - Προτάσεις υλοποίησης

Η εφαρμογή στην παρούσα μελέτη του διεθνούς προτύπου CIDOC CRM και των επεκτάσεων του στην κατεύθυνση της τεκμηρίωσης της ανασκαφικής διαδικασίας με αρχιτεκτονικά λείψανα είχε ως αποτέλεσμα τη δημιουργία ενός μοντέλου αναπαράστασης γνώσης από το οποίο μπορούν να προκύψουν συμπεράσματα σχετικά με: α) το είδος και τις σχέσεις των αρχαιολογικών δεδομένων που πρέπει να μοντελοποιηθούν και β) τη σημασία της διασύνδεσης των δεδομένων των αρχιτεκτονικών λειψάνων με το ανασκαφικό περιβάλλον στο οποίο βρέθηκαν.

Σε σημασιολογικό επίπεδο, μέσα από αυτή τη διαδικασία διαπιστώθηκε ότι η χρήση του CIDOC CRM και των συμβατών επεκτάσεών του επιτρέπει μια ορθή και λειτουργική αναπαράσταση της γνώσης σχετικά με τα ανασκαφικά δεδομένα. Ο τρόπος συνδυασμού των διαφόρων επεκτάσεων είναι μια διαδικασία δύσκολη αλλά η εξειδικευμένη τεκμηρίωση πληροφοριών που αυτές προσφέρουν έχει σημαντικά οφέλη.

Η συνέχεια αυτής της έρευνας απαιτεί την εφαρμογή του προτεινόμενου μοντέλου και σε άλλες περιπτώσεις ανασκαφών αρχαιολογικών κτηρίων έτσι ώστε να εξεταστούν πιθανές επεκτάσεις του για τη σωστή αναπαράσταση των διαφόρων φάσεων του κτηρίου στο χρόνο και τον χώρο, καθώς και τη χρονική διάρκεια των τοπολογικών σχέσεων μεταξύ των επιμέρους τμημάτων του, όπως για παράδειγμα την υποστήριξη της εικονικής αναπαράστασής του. Η παρούσα μελέτη μπορεί να συμβάλει ταυτόχρονα και στην περαιτέρω εξέλιξη των επεκτάσεων CRMarchaeo και CRMba στους παραπάνω τομείς.

Τέλος, η διευκόλυνση και παρακολούθηση της δόμησης της επιχειρηματολογίας (ομαδοποίηση των επιχειρημάτων, παρακολούθηση προέλευσης της πληροφορίας και κριτική του περιεχομένου τους) ως προς την ερμηνεία του παρελθόντος όπως αυτή παρουσιάστηκε στο προτεινόμενο μοντέλο με τη χρήση του CRMinf, μπορεί να εφαρμοστεί μελλοντικά σε ένα ηλεκτρονικό αποθετήριο που να βασίζεται στη δυνατότητα του υπεύθυνου αρχαιολόγου να οργανώνει, να διαχειρίζεται και να αποθηκεύει ταυτόχρονα και με ολοκληρωμένο τρόπο, όλες τις πληροφορίες μιας πολύπλοκης και πολύπλευρης ανασκαφικής διαδικασίας ενός αρχαιολογικού κτηρίου, από το αρχικό στάδιο μιας επιφανειακής έρευνας μέχρι τη δημοσίευση των τελικών αποτελεσμάτων.

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ΠΟΣΟΤΙΚΕΣ ΜΕΘΟΔΟΙ ΣΤΗ ΔΙΕΡΕΥΝΗΣΗ ΤΩΝ ΕΠΙΔΡΑΣΕΩΝ ΤΩΝ ΠΕΡΙΒΑΛΛΟΝΤΙΚΩΝ ΠΑΡΑΓΟΝΤΩΝ ΣΤΑ ΟΡΓΑΝΙΚΑ ΥΛΙΚΑ ΤΕΚΜΗΡΙΑ ΦΥΣΙΚΗΣ ΚΑΙ ΠΟΛΙΤΙΣΤΙΚΗΣ ΚΛΗΡΟΝΟΜΙΑΣ - Η ΠΕΡΙΠΤΩΣΗ ΤΟΥ ΟΣΤΟΥ

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Περίληψη/Abstract

Στην παρούσα εργασία, παρουσιάζεται η έρευνα της επίδρασης διαφόρων παραγόντων γήρανσης στις φυσικές και χημικές ιδιότητες οστέινων αντικειμένων πολιτιστικής κληρονομιάς. Πραγματοποιήθηκαν μετρήσεις σε τεχνητώς γηρασμένα δείγματα από σύγχρονα οστά ζαρκαδιού (roe deer - *Capreolus capreolus*). Εξετάστηκαν παράγοντες γήρανσης με 2 επίπεδα ο καθένας: υγρασία, χρόνος έκθεσης, επίδραση των νιτρικών και θειικών ιόντων (NOx και SOx) καθώς και η σειρά με την οποία οι δύο παραπάνω ρυπαντές επέδρασαν. Το πείραμα βασίστηκε σε ένα 2^4 fractional factorial design. Εφαρμόζοντας ANOVA συμπεράναμε ότι τα είδη των ρυπαντών που χρησιμοποιηθήκαν βρέθηκαν να είναι στατιστικά σημαντικά συσχετιζόμενα με τις μεταβλητές του χρώματος, ενώ η σειρά με την οποία εφαρμόστηκε η έκθεση σε αυτούς βρέθηκε στατιστικά σημαντικά συσχετιζόμενη με τις ιδιότητες χρώματος, τη σκληρότητα και τις μηχανικές ιδιότητες. Η υγρασία παρουσίασε στατιστικά σημαντική συσχέτιση με μεταβλητές που αφορούσαν στη σκληρότητα, τις μηχανικές ιδιότητες, τη χημική σταθερότητα και τη μορφολογία. Τέλος, η διάρκεια ήταν στατιστικά σημαντική για τη χημική σταθερότητα και τη μορφολογία.

This paper presents the research on various aging factors’ effect on the physical and chemical properties of bone artefacts of cultural heritage. Measurements on artificially aged samples of fresh roe deer bones (Capreolus) have been carried out. Aging factors have been examined in two levels: moisture, exposure time, influence of NOx and SOx and the order in which the two above contaminants reacted. The experiment was based on a 2^4 fractional factorial design. By applying ANOVA it was concluded that all the kinds of contaminants used in this experiment were statistically significant correlated with the colour variables while the order of exposure was found to be statistically significant correlated with the colour, the hardness and the mechanical properties. Humidity was statistically significant correlated with variables related to hardness, mechanical properties, chemical stability and morphology. Finally the time of exposure was statistically significant for the chemical stability and the morphology.

Λέξεις Κλειδιά: Οστό, Παράγοντες Γήρανσης, Τεχνητή Γήρανση, ANOVA, Fractional Factorial Design

1. Εισαγωγή

Τα πλέον ευαίσθητα υλικά μεταξύ όσων απαρτίζουν την πολιτιστική κληρονομιά είναι τα οργανικά υλικά, τόσο τα ζωικής προέλευσης, δηλαδή τα πρωτεϊνικά υλικά (π.χ. οστό, κέρατο, ελεφαντόδοντο, δέρμα, περγαμηνή, μάλλινο ύφασμα, μετάξι κ.ά.) (Karpovicz 1989), όσο και τα φυτικής προέλευσης, δηλαδή τα κυτταρινικά ή λιγνοκυτταρινικά υλικά (π.χ. ξύλο, χαρτί, ψαθί, βαμβακερό ή λινό ύφασμα κ.ά.) (Rivers & Umney 2005, Erhardt & Mecklenburg 1995). Μεγαλύτερο δε πρόβλημα αντιμετωπίζουν τα οργανικά υλικά που δεν έχουν υποστεί επεξεργασία, δεν έχει δηλαδή εφαρμοστεί σε αυτά κάποια μέθοδος συντήρησης που να ενισχύει την ανθεκτικότητα και την αντοχή τους. Τα υλικά, αυτά φιλοξενούνται κυρίως σε αρχεία-βιβλιοθήκες, λαογραφικές συλλογές, επιστημονικά μουσεία, μουσεία φυσικής ιστορίας, ιστορικά και αρχαιολογικά μουσεία.

Η ατμοσφαιρική ρύπανση, οι ακατάλληλες τιμές αλλά και οι μεταβολές της ατμοσφαιρικής θερμοκρασίας και υγρασίας, το φως, οι μικροοργανισμοί κ.λπ. στους μουσειακούς χώρους μπορούν να οδηγήσουν ακόμα και σε ραγδαία αποδόμηση αυτών των υλικών (EnviArt, George *et al.* 2005, Hedges 2002, Davidson 1996, Riganti *et al.* 1995, Harris 1984, Upham & Salvin 1975). Για το λόγο αυτό στους κόλπους της μουσειακής κοινότητας θεωρείται μείζονος σημασίας ο προσδιορισμός και η διασφάλιση των καταλληλότερων περιβαλλοντικών συνθηκών, για την προληπτική συντήρηση των ανωτέρω υλικών (σε συνθήκες αποθήκευσης, έκθεσης ή και μεταφοράς τεχνουργημάτων) (Dahlin 2010, Gysels *et al.* 2004, Camuffo 1998, Weintraub & Wolf 1995, Brimblecombe 1990).

Στο πλαίσιο αυτό το Τμήμα Συντήρησης Αρχαιοτήτων & Έργων Τέχνης του ΤΕΙ Αθήνας σε συνεργασία με άλλα ΑΕΙ της Ελλάδας και του Εξωτερικού πραγματοποίησε το ερευνητικό πρόγραμμα ΘΑΛΗΣ, 2012-2015, «Διερεύνηση των Επιδράσεων των Περιβαλλοντικών Παραγόντων στα Οργανικά Υλικά Τεκμήρια Φυσικής και Πολιτιστικής Κληρονομιάς».

Σκοπός του προγράμματος ήταν να μελετηθεί με έναν επιστημονικά πλήρη και αποδεκτό τρόπο η επίδραση διαφόρων παραγόντων στη γήρανση πολιτιστικών τεκμηρίων οργανικής σύστασης. Συγκεκριμένα χρησιμοποιήθηκαν 5 διαφορετικά μη επεξεργασμένα οργανικά υλικά: οστό, ξύλο, χαρτί, ύφασμα, περγαμηνή. Στην παρούσα εργασία, παρουσιάζεται η έρευνα της επίδρασης διαφόρων παραγόντων γήρανσης στις φυσικές και χημικές ιδιότητες οστέινων αντικειμένων πολιτιστικής κληρονομιάς.

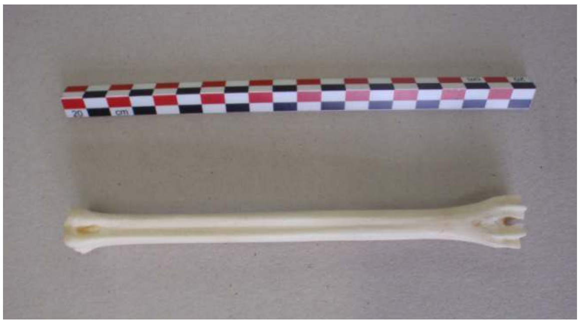
Ένα από τα μεγάλα πλεονεκτήματα του παρόντος έργου είναι η χρήση πειραματικών σχεδιασμών για τη μελέτη δοκιμίων σχετικά με τη συντήρηση αρχαιοτήτων και έργων τέχνης. Η ανάγκη δημιουργίας πειραματικού σχεδιασμού στο εν λόγω πεδίο, αλλά και εν γένει η ορθή αξιοποίηση της στατιστικής στην αρχαιολογία και στη συντήρηση είναι αντικείμενο επιστημονικής συζήτησης για περισσότερο από 20 χρόνια (Box 1980, Chambers *et al.* 1992).

Το συγκεκριμένο πείραμα βασίστηκε πάνω σε ένα στατιστικό πειραματικό σχεδιασμό ώστε να ελαχιστοποιηθεί ο αριθμός των δοκιμών (και άρα να ικανοποιηθούν περιορισμοί κόστους και χρόνου) χωρίς όμως να απολεσθεί η δυνατότητα πλήρους στατιστικής ανάλυσης. Ο πλήρης σχεδιασμός και η εκτέλεση ενός τέτοιου πειράματος είναι πρωτοποριακός στο πεδίο της συντήρησης της πολιτιστικής κληρονομιάς.

2. Υλικά και μέθοδοι

Η γήρανση των οργανικών υλικών μελετήθηκε τόσο τεχνητά με κατάλληλα σχεδιασμένο πείραμα σε σχέση με προκαθορισμένους παράγοντες όπου τα υλικά τοποθετήθηκαν σε πειραματικό θάλαμο, όσο και φυσικά τοποθετώντας τα υλικά για δύο χρόνια σε μουσεία, μέσα και έξω από προθήκες.

Στην παρούσα εργασία παρουσιάζονται τα αποτελέσματα της τεχνητής γήρανσης στην περίπτωση του οστού. Τα δείγματα που χρησιμοποιήθηκαν (Εικ. 1), ήταν μεταταρσικά οστά ζαρκαδιού (roe deer – *Capreolus capreolus*).



Εικόνα 1 Δείγματα οστού - μεταταρσικά οστά ζαρκαδιού (roe deer – *Capreolus capreolus*).

Δύο ήταν οι βασικές δυσκολίες που έπρεπε να υπερκεραστούν. Αφενός η διαφορετική γεωμετρία του κάθε δείγματος οστού και αφετέρου η ανομοιογένεια του υλικού του οστού η οποία και αυξάνεται με την διαδικασία γήρανσης. Η αντιμετώπιση και στα δύο αυτά προβλήματα ήταν η CT scanning analysis.

Η τεχνητή γήρανση πραγματοποιήθηκε σε πειραματική συσκευή τεχνητής γήρανσης (Εικόνα 2), που δημιουργήθηκε στο Τμήμα Χημικών Μηχανικών του Πανεπιστημίου Πατρών.

Εικόνα 2 Πειραματική συσκευή τεχνητής γήρανσης.

Πραγματοποιήθηκαν μετρήσεις σε διάφορα χαρακτηριστικά που σχετίζονται με τις οπτικές, μηχανικές και χημικές ιδιότητες του οστού καθώς και με τη δομή και τη μορφολογία του. Συγκεκριμένα, αναφορικά με τις οπτικές ιδιότητες εξετάστηκε το χρώμα και η στιλπνότητα. Η χρωματομέτρηση επιτρέπει τον προσδιορισμό της μεταβολής του χρώματος των δοκιμίων οστού, μέσω των συντεταγμένων χρώματος L*, a* και b*, του CIE lab σύμφωνα με το πρότυπο «ASTM D 2244-93». Το χρωματικό μοντέλο L*a*b αναλύει το χρώμα του κάθε εικονοστοιχείου σε τρεις παραμέτρους. Στην παράμετρο L αντιστοιχεί η ένταση φωτεινότητας, στην a υποδηλώνεται η χρωματική θέση ανάμεσα στον άξονα κόκκινου και πράσινου και στη b η θέση ανάμεσα στο κίτρινο και το μπλε. Η χρωματομέτρηση πραγματοποιήθηκε με την βοήθεια της FE method (finite elements) δηλαδή την αριθμητική μέθοδο πεπερασμένων στοιχείων με χρήση μερικών διαφορικών εξισώσεων. Η στιλπνότητα (gloss) είναι μια οπτική ιδιότητα που περιγράφει την κατοπτρική ανάκλαση του φωτός. Η γωνία ανάκλασης εξαρτάται από φυσικά χαρακτηριστικά της επιφάνειας, όπως η τραχύτητα.

Αναφορικά με τις μηχανικές ιδιότητες ελέγχθηκαν μεταξύ άλλων, η αντοχή στην κάμψη τριών σημείων, η πυκνότητα, ο όγκος και έγινε σκληρομέτρηση κατά Vickers. Σκληρότητα είναι ένα μέτρο της αντίστασης ενός υλικού όταν διαπερνάται από έναν διεισδυτή. Επιπλέον, μέσω ενός Ηλεκτρονικού Μικροσκοπίου Σάρωσης εφοδιασμένου με φασματογράφο ενεργειακής διασποράς των ακτίνων-X (SEM-EDS) πραγματοποιήθηκε ημιποσοτική ανάλυση των στοιχείων Al, C, Ca, Mg, N, Na, O, P, S του υλικού. Τέλος αναφορικά με τη σύνθεση και χημική σταθερότητα οι μετρήσεις αφορούσαν σε αντισώματα κολλαγόνου κ.λπ.

Τα αποτελέσματα συσχετίστηκαν με τα δεδομένα αξιολόγησης της κατάστασης διατήρησης των δοκιμίων με τη μέθοδο της χημειομετρίας (chemometrics). Τα βήματα της διαδικασίας που ακολουθήθηκε ήταν τα εξής:

1. Πειραματικός Σχεδιασμός
2. Προετοιμασία των δοκιμίων του υλικού
3. Τεχνητή γήρανση σε θάλαμο
4. Συλλογή Αναλυτικών Δεδομένων με τη χρήση κατάλληλων τεχνικών
5. Έλεγχος των δεδομένων για λογική συνέπεια (π.χ. ακραίες τιμές, χειρισμός ελλιπών δεδομένων κ.λπ.)
6. Στατιστική ανάλυση.

3. Στατιστική Ανάλυση

Οι πειραματικοί σχεδιασμοί (Dellaportas *et al.* 2014) προσφέρουν πολλά πλεονεκτήματα όπως:

• ελαχιστοποιούν το μέγεθος δείγματος, και έτσι δεν πραγματοποιούνται περισσότερα πειράματα από όσα χρειάζονται για να πάρουμε την ίδια πληροφορία,
• επιτρέπουν την εκτίμηση των μεγεθών που μας ενδιαφέρουν,
• ελαχιστοποιούν το κόστος καθώς το πείραμα περιλαμβάνει μόνο τις απαραίτητες επαναλήψεις.

Η θεωρία των πειραματικών σχεδιασμών αποτελεί τη βάση της σχεδίασης πειραμάτων σε όλες τις επιστημονικές κατευθύνσεις.

Οι k ανεξάρτητες μεταβλητές, η επίδραση των οποίων σε κάποια εξαρτημένη μεταβλητή (απόκριση) πρόκειται να μελετηθεί, ονομάζονται παράγοντες (factors). Ένα πείραμα με k παράγοντες, με τον κάθε παράγοντα σε 2 επίπεδα, ονομάζεται παραγοντικό πείραμα 2 επιπέδων (factorial design) και συμβολίζεται ως 2^k . Ένα πλήρες παραγοντικό πείραμα 2^k απαιτεί να υλοποιηθούν 2^k πειράματα (χωρίς επανάληψη), που αποτελούν όλους τους συνδυασμούς των k παραγόντων μεταξύ τους σε 2 επίπεδα. Οι παράγοντες (δηλ. οι ανεξάρτητες μεταβλητές) μπορεί να είναι συνεχείς (π.χ. πίεση, θερμοκρασία κ.λπ.) ή ασυνεχείς (π.χ. παρουσία ή όχι κάποιου υλικού, χρήση ή όχι κάποιας συνθήκης κ.λπ.). Η μεταβλητή απόκρισης (response variable), που αποτελεί την εξαρτημένη μεταβλητή του πειράματος, και που θα ονομάζεται πλέον απόκριση, συνήθως συμβολίζεται με Y. Υπάρχουν και παραγοντικά πειράματα που απαιτούν λιγότερο των 2^k πειραμάτων ώστε να μελετηθούν οι k παράγοντες. Αυτά ονομάζονται κλασματικά (ή μερικά) παραγοντικά πειράματα (fractional factorial designs) και απαιτούν ακόμα μικρότερο αριθμό πειραμάτων για την μελέτη k παραγόντων (Κομίλης 2006).

Για παράδειγμα αν έχουμε να εξετάσουμε 5 παράγοντες εκ των οποίων οι 3 πρώτοι έχουν 2 επίπεδα, ο $4^{ος}$ παράγοντας έχει 3 επίπεδα και τέλος ο $5^{ος}$ παράγοντας έχει 5 επίπεδα, τότε θα πρέπει να εκτελέσουμε 2 x 2 x 2 x 3 x 5 = 120 πειράματα προκειμένου να εξαντληθούν όλοι οι δυνατοί συνδυασμοί. Αυτό σημαίνει πως, αν και οι παραγοντικοί σχεδιασμοί είναι ο πιο απλός τρόπος για να μελετήσουμε αυτό που επιθυμούμε, μπορεί να οδηγήσουν σε αριθμό πειραμάτων που είναι οικονομικά ασύμφορος κα ίσως δεν ικανοποιεί περιορισμούς χρόνου και κόστους.

Οι κλασματικοί παραγοντικοί σχεδιασμοί, αντί να χρησιμοποιούν όλους τους δυνατούς συνδυασμούς όπως είδαμε για την περίπτωση των παραγοντικών σχεδιασμών, επιλέγουν με βάση κάποια αυστηρά κριτήρια ένα υποσύνολο από όλους τους συνδυασμούς. Το πλεονέκτημα είναι ότι με αυτόν τον τρόπο ο αριθμός των πειραμάτων μειώνεται. Η προσεκτική επιλογή των συνδυασμών ακολουθεί τα κριτήρια «κόστους – οφέλους» στην πειραματική διαδικασία. Είναι βέβαια σαφές ότι με τον τρόπο αυτό κάποιες αλληλεπιδράσεις δεν είναι πλέον εκτιμήσιμες, και αυτό αποτελεί τη «θυσία πληροφορίας» ώστε να μειωθεί ο αριθμός των πειραμάτων και το κόστος.

Σε ένα πείραμα με πέντε δυαδικούς παράγοντες όπως το παρόν, όλοι οι συνδυασμοί για ένα πλήρη παραγοντικό σχεδιασμό είναι 2^5 (τριάντα δύο). Συνήθως ένας κλασματικός παραγοντικός σχεδιασμός χρησιμοποιεί λιγότερους συνδυασμούς και συγκεκριμένα το πλήθος 2^{5-p} , όπου ανάλογα με την τιμή που παίρνει το p μειώνεται και ο αριθμός των απαιτούμενων πειραμάτων. Για παράδειγμα για p=1 θα καταλήξουμε σε 16 πειράματα, για p=2 σε 8 πειράματα και ούτω καθεξής. Αυτό που συνήθως θυσιάζουμε είναι οι μειωμένου ενδιαφέροντος αλληλεπιδράσεις μεγάλου βαθμού.

Στο παρόν έργο, επιλέχθηκε να εξεταστούν οι κάτωθι πέντε παράγοντες, σε δύο επίπεδα ο καθένας:

- η υγρασία (45% και 70%)
- η διάρκεια (24 και 48 μέρες)
- η επίδραση του NOx (100 και 300 ppm)
- η επίδραση του SOx(100 και 300 ppm)
- η σειρά με την οποία οι δυο παραπάνω ρυπαντές επέδρασαν, δηλαδή πρώτα η έκθεση σε NOx και μετά σε SOx (N/S) και το αντίστροφο (S/N).

Ο 2^{5-1} (δεκαέξι) fractional factorial σχεδιασμός για το έργο αναλύεται στον Πίνακα 1.

Experiment	Duration in days	Relative humidity (%)	Nox in ppm	Sox in ppm	Pollutant order
1	14	45	100	300	N/S
2	28	70	300	100	N/S
3	28	70	100	300	N/S
4	28	70	100	100	S/N
5	14	70	300	300	N/S
6	28	45	300	100	S/N
7	14	70	100	100	N/S
8	28	45	300	300	N/S
9	28	45	100	300	S/N
10	28	70	300	300	S/N
11	28	45	100	100	N/S
12	14	45	300	100	N/S
13	14	70	100	300	S/N
14	14	45	300	300	S/N
15	14	45	100	100	S/N
16	14	70	300	100	S/N

Πίνακας 1 Ο 2^{5-1} fractional factorial σχεδιασμός για το έργο.

Για κάθε μία από αυτές τις 16 διαφορετικές πειραματικές καταστάσεις συλλέχθηκε ένας αριθμός δειγμάτων, ώστε να υπάρχει η δυνατότητα καλύτερης στατιστικής ανάλυσης. Ο αριθμός δειγμάτων που επιλέχθηκε είναι τρία για κάθε πείραμα κι επομένως ήταν διαθέσιμες 48 παρατηρήσεις για κάθε μεταβλητή. Στη συνέχεια έγινε εκκαθάριση δεδομένων, περιγραφική ανάλυση των δεδομένων, και εφαρμόστηκαν στατιστικές τεχνικές όπως ANOVA και μέθοδοι μείωσης των διαστάσεων του προβλήματος.

4. Αποτελέσματα

Διάφορα περιγραφικά μέτρα υπολογίστηκαν για όλες τις μεταβλητές (Πιν. 2). Παρατηρείται ότι για τις περισσότερες μεταβλητές - μετρήσεις τα δεδομένα ήταν σχετικά συμμετρικά (όπως η στιλπνότητα, το χρώμα κ.λπ.). Ασυμμετρίες παρατηρήθηκαν κυρίως στις μηχανικές μεταβλητές.

	Μέτρηση	min	1st Q	Median	Mean	3rd Q	Max
χρώμα	L	54.300	78.700	80.840	79.210	82.460	85.830
	a	-0.36	1.768	2.585	2.824	3.825	7.090
	b	15.050	20.340	24.320	24.140	27.800	41.990
στιλπνότητα	sideA_20	1.700	2.500	2.700	2.650	2.900	3.200
	sideA_60	1.700	2.100	2.400	2.490	2.700	3.900
	sideA_75	1.200	2.800	4.400	4.498	5.500	12.300
	sideB_20	1.400	2.600	2.700	2.731	2.925	3.500
	sideB_60	1.500	2.475	2.650	2.685	3.000	3.500
	sideB_75	1.400	3.575	5.150	5.296	6.475	9.300
	sideC_20	1.600	2.400	2.600	2.569	2.800	3.200
	sideC_60	1.500	2.300	2.500	2.565	2.825	3.500
	sideC_75	1.400	3.800	4.900	5.135	6.500	11.000
χημική σταθερότητα	anti-collagen	0.094	0.18	0.217	0.292	0.372	0.719
	anti-[Pro-Ser(OBzl)-Gly]n	0.051	0.241	0.413	0.409	0.545	0.817
σκληρότητα	HV_1	48.750	64.150	77.170	73.350	82.400	94.590
	HV_2	51.350	68.090	77.170	74.020	82.400	94.590
	HV_3	54.170	68.100	77.170	76.050	82.400	94.590
	Μέση τιμή	51.420	67.540	77.170	74.470	82.580	90.320
μηχανικές ιδιότητες	Maximum Uz displacement	0.045	0.093	0.136	0.211	0.205	1.383
	Minimum Uz displacement	-0.108	-0.023	-0.01	-0.02	-0.004	0
	Maximum Von	266	463	695	820	999	3977
	Maximum Von	0.004	0.006	0.008	0.018	0.022	0.124
	Maximum Strain	0.385	0.878	1.285	2.654	2.617	24.590
	Minimum E3 Strain	-0.097	-0.006	-0.003	-0.008	-0.002	-0.001
	Maximum Volume	2.813	3.596	4.134	4.341	4.728	8.356
	Minimum Volume	0.002	0.009	0.014	0.014	0.019	0.033
	Mean Volume	0.458	0.513	0.618	0.696	0.851	1.070
	Variance Volume	0.069	0.11	0.17	0.208	0.282	0.467
	StrainEnergyDensity	311.3	456.6	714.0	938.0	888.1	5593.0
	Volume	6.049	8.094	9.565	9.184	10.260	11.910

Πίνακας 2 Περιγραφικά μέτρα για τις μεταβλητές.

Ακολούθησε ανάλυση διακύμανσης (ANOVA) (Chambers *et al.* 1992) στα δεδομένα του πειράματος όπως ήταν σχεδιασμένο από την αρχή χωρίς τη χρήση αλληλεπιδράσεων στα μοντέλα αυτά. Τα αποτελέσματα περιγράφονται εν συντομία στους ακόλουθους Πίνακες 3 - 8. Οι αλληλεπιδράσεις μελετήθηκαν ξεχωριστά με περιγραφικό κυρίως τρόπο.

Main effect	Level	L		a		b	
		(p=0.021)		(p<0.001)		(p=0<0.001)	
		Avg(std)	p-value	Avg(std)	p-value	Avg(std)	p-value
OVERALL		79.2 (6.5)		2.8 (1.8)		24.1 (5.3)	
Duration (Days)	14	80.6 (4.2)	0.098	3.0 (1.8)	0.45	24.8 (5.8)	0.17
	28	77.8 (8.0)		2.7 (1.8)		23.5 (4.8)	
Relative Humidity % (RH)	45	80.7 (3.9)	0.092	2.9 (1.9)	0.82	24.7 (6.2)	0.25
	70	77.7 (8.1)		2.8 (1.7)		23.6 (4.3)	
Concentration SOx (ppm)	100	79.5 (4.7)	0.69	3.4 (1.6)	0.0029	24.7 (4.0)	0.31
	300	78.9 (7.9)		2.2 (1.8)		23.6 (6.4)	
Concentration NOx (ppm)	100	80.6 (6.8)	0.11	1.9 (1.6)	<.0001	22.6 (5.9)	0.0037
	300	77.8 (5.9)		3.8 (1.5)		25.7 (4.2)	
Pollutant order	N/S	77.1 (7.3)	0.016	3.5 (1.5)	0.0005	27.9 (4.2)	<.0001
	S/N	81.3 (4.7)		2.1 (1.8)		20.4 (3.3)	

Πίνακας 3 ANOVA για τις μεταβλητές χρώματος.

Στον Πίνακα 3 μπορεί κανείς να δει τις τρεις μεταβλητές για το χρώμα (L, a, b). Για τη μεταβλητή L το συνολικό p-value είναι 0.021 κάτι που σημαίνει ότι τουλάχιστον ένας παράγοντας είναι στατιστικά σημαντικός. Η συνολική μέση τιμή είναι 79.2 και η συνολική τυπική απόκλιση 6.5. Κοιτάζοντας κάθε παράγοντα ξεχωριστά, η μέση τιμή για διάρκεια γήρανσης 14 μέρες είναι 80.6 ενώ η τυπική απόκλιση 4.2. Το p-value είναι 0.098 κάτι που σημαίνει ότι σε επίπεδο α=5% δεν απορρίπτουμε τη μηδενική υπόθεση ότι δηλαδή ο παράγοντας δεν είναι στατιστικά σημαντικός. Συνεπώς δεν μπορούμε να ισχυριστούμε ότι ο παράγοντας «διάρκεια» είναι σημαντικός για τη μεταβλητή L. Ερμηνεύοντας τα υπόλοιπα στοιχεία του πίνακα καθώς και τους επόμενους Πίνακες 4 - 8 με παρόμοιο τρόπο, επισημαίνουμε με κόκκινο τις τιμές του p-value που υποδηλώνουν στατιστικά σημαντική σχέση.

Main effect	Level	Side A (p=0.98)		Side B (p=0.61)		Side C (p=0.78)	
		Avg(std)	p-value	Avg(std)	p-value	Avg(std)	p-value
Duration	14	2.43 (0.45)	0.83	2.86 (0.39)	0.30	2.83 (0.38)	0.90
(Days)	28	2.4 (0.35)		2.88 (0.29)		2.77 (0.39)	
Relative Humidity	45	2.33 (0.21)	0.76	2.82 (0.42)	0.70	2.98 (0.28)	0.16
% (RH)	70	2.45 (0.44)		2.89 (0.3)		2.72 (0.39)	
Concentration SOx	100	2.45 (0.41)	0.57	2.85 (0.23)	0.70	2.78 (0.4)	0.69
(ppm)	300	2.37 (0.37)		2.9 (0.45)		2.81 (0.37)	
Concentration NOx	100	2.4 (0.38)	0.87	2.95 (0.35)	0.20	2.82 (0.42)	0.66
(ppm)	300	2.43 (0.42)		2.77 (0.29)		2.77 (0.34)	
Pollutant order	N/S	2.43 (0.46)	0.76	2.92 (0.37)	0.20	2.8 (0.38)	0.55
	S/N	2.37 (0.12)		2.75 (0.16)		2.78 (0.41)	

Πίνακας 4 ΑΝΟVA για τις μεταβλητές στιλπνότητας.

Στον Πίνακα 5 παρατηρούμε ότι το κολλαγόνο επηρεάζεται από τη διάρκεια και τη σχετική υγρασία.

Main effect	Level	Collagen antibodies (p=0.39)		[Pro-Ser(OBzl)-Gly]n antibodies (p=0.021)	
		Avg(std)	p-value	Avg(std)	p-value
OVERALL		0.29 (0.18)		0.41 (0.18)	
Duration (Days)	14	0.33 (0.18)	0.14	0.36 (0.19)	0.037
	28	0.25 (0.17)		0.46 (0.15)	
Relative Humidity % (RH)	45	0.28 (0.20)	0.69	0.36 (0.15)	0.028
	70	0.30 (0.16)		0.46 (0.19)	
Concentration SOx (ppm)	100	0.30 (0.20)	0.79	0.37 (0.17)	0.084
	300	0.29 (0.15)		0.45 (0.18)	
Concentration NOx (ppm)	100	0.28 (0.18)	0.78	0.41 (0.15)	0.98
	300	0.30 (0.17)		0.41 (0.20)	
Pollutant order	N/S	0.25 (0.17)	0.11	0.44 (0.16)	0.15
	S/N	0.33 (0.18)		0.38 (0.19)	

Πίνακας 5 ΑΝΟVA για τις μεταβλητές σύνθεσης και χημικής σταθερότητας.

Στους Πίνακες 6α και 6β παρατηρούμε ότι ο φώσφορος και το ασβέστιο που είναι τα βασικά στοιχεία του ανόργανου μέρους του οστού (υδροξυαπατίτης), επηρεάζονται από την σχετική υγρασία.

Main effect	Level	Al (p=0.53)		C (p=0.48)		Ca (p=0.027)	
		Avg(std)	p-value	Avg(std)	p-value	Avg(std)	p-value
Duration	14	0.31 (0.79)	0.84	35.69 (8.04)	0.88	12.36 (2.37)	0.19
(Days)	28	0.08 (0.08)		32.46 (7.06)		14.41 (2.68)	
Relative Humidity	45	0.45 (0.97)	0.17	37.45 (7.9)	0.16	10.82 (2.36)	0.01
% (RH)	70	0.07 (0.07)		32.39 (7.06)		14.61 (2)	
Concentration SOx	100	0.07 (0.08)	0.76	31.63 (5.61)	0.55	13.93 (2.64)	0.84
(ppm)	300	0.32 (0.79)		36.78 (8.92)		12.99 (2.84)	
Concentration NOx	100	0.27 (0.68)	0.38	34.5 (9.58)	0.69	13.7 (2.96)	0.73
(ppm)	300	0.05 (0.03)		32.95 (3.47)		13.31 (2.47)	
Pollutant order	N/S	0.21 (0.61)	0.76	34.86 (8.16)	0.47	13.48 (2.62)	0.75
	S/N	0.1 (0.1)		31.3 (5.17)		13.65 (3.15)	

Πίνακας 6α ΑΝΟVA για τις μεταβλητές δομής.

Main effect	Level	O (p=0.94)		P (p=0.26)		S (p=0.34)	
		Avg(std)	p-value	Avg(std)	p-value	Avg(std)	p-value
Duration	14	34.1 (5.29)	0.44	6.62 (1.47)	0.77	1 (0.34)	0.90
(Days)	28	33.61 (4.71)		6.94 (1.58)		0.89 (0.36)	
Relative Humidity	45	33.65 (4.68)	0.71	5.59 (1.07)	0.04	0.78 (0.23)	0.28
% (RH)	70	33.89 (5.06)		7.29 (1.39)		1 (0.37)	
Concentration SOx	100	34.51 (3.74)	0.70	7.13 (1.4)	0.52	0.88 (0.24)	0.76
(ppm)	300	32.91 (6.14)		6.36 (1.6)		1.01 (0.44)	
Concentration NOx	100	33.91 (5.93)	0.96	6.72 (1.7)	0.70	0.86 (0.32)	0.15
(ppm)	300	33.7 (3.2)		6.9 (1.29)		1.04 (0.37)	
Pollutant order	N/S	33.37 (5.47)	0.51	6.81 (1.53)	0.77	1.02 (0.38)	0.48
	S/N	34.96 (2.78)		6.78 (1.58)		0.74 (0.08)	

Πίνακας 6β ΑΝΟVA για τις μεταβλητές δομής.

Στον Πίνακα 6γ παρατηρούμε ότι το άζωτο που αποτελεί στοιχείο του οργανικού μέρους του οστού (κολλαγόνο), επηρεάζεται από τη διάρκεια τη σχετική υγρασία και τη συγκέντρωση θειούχων αερίων ρυπαντών.

Main effect	Level	Mg (p=0.44)		N (p=0.012)		Na (p=0.16)	
		Avg(std)	p-value	Avg(std)	p-value	Avg(std)	p-value
Duration	14	0.22 (0.04)	0.54	11.54 (1.36)	0.08	0.22 (0.05)	0.57
(Days)	28	0.21 (0.05)		11.87 (1.52)		0.22 (0.08)	
Relative Humidity	45	0.19 (0.02)	0.13	12.97 (0.66)	0.01	0.16 (0.03)	0.06
% (RH)	70	0.23 (0.05)		11.23 (1.36)		0.24 (0.06)	
Concentration SOx	100	0.22 (0.04)	0.49	11.3 (1.62)	0.07	0.22 (0.08)	0.88
(ppm)	300	0.21 (0.05)		12.3 (0.93)		0.23 (0.06)	
Concentration NOx	100	0.22 (0.05)	0.48	11.39 (1.64)	0.18	0.23 (0.06)	0.44
(ppm)	300	0.21 (0.03)		12.18 (1.01)		0.2 (0.08)	
Pollutant order	N/S	0.22 (0.05)	0.92	11.71 (1.18)	0.53	0.23 (0.07)	0.51
	S/N	0.21 (0.04)		11.78 (2.06)		0.19 (0.07)	

Πίνακας 6γ ΑΝΟVA για τις μεταβλητές δομής.

Στον Πίνακα 7 παρατηρούμε ότι η σκληρότητα κατά Vickers επηρεάζεται από τη σχετική υγρασία και τη σειρά με την οποία εφαρμόστηκε η έκθεση σε NOx και SOx.

Main effect	Level	Mean VH	
		Avg(std)	p-value
OVERALL		74.47 (11.20)	
Duration (Days)	14	75.00 (11.25)	0.81
	28	73.95 (11.38)	
Relative Humidity % (RH)	45	71.15 (11.28)	0.039
	70	77.79 (10.31)	
Concentration SOx (ppm)	100	75.10 (12.14)	0.65
	300	73.85 (10.42)	
Concentration NOx (ppm)	100	75.41 (12.18)	0.62
	300	73.54 (10.32)	
Pollutant order	N/S	78.47 (5.92)	0.018
	S/N	70.81 (13.57)	

Πίνακας 7 ΑΝΟVA για τις μεταβλητές μηχανικών ιδιοτήτων – Σκληρότητα κατά Vickers.

Στον Πίνακα 8 παρατηρούμε ότι οι μηχανικές ιδιότητες επηρεάζονται από τη σχετική υγρασία και τη σειρά με την οποία εφαρμόστηκε η έκθεση σε NOx και SOx.

Main effect	Level	Mesh evaluation (mean vol. el)		Strain Energy Density		Volume	
		(p=0.025)		(p=0.083)		(p=0.25)	
		Avg(std)	p-value	Avg(std)	p-value	Avg(std)	p-value
OVERALL		0.70 (0.20)		938.0 (1033)		9184 (1542)	
Duration (Days)	14	0.66 (0.17)	0.18	724.8 (360.0)	0.14	9043 (1517)	0.53
	28	0.73 (0.23)		1151 (1399)		9325 (1586)	
Relative Humidity % (RH)	45	0.63 (0.19)	0.011	1190 (1384)	0.082	9496 (1267)	0.16
	70	0.77 (0.19)		686.3 (368.8)		8872 (1746)	
Concentration SOx (ppm)	100	0.72 (0.20)	0.28	779.3 (415.8)	0.267	8939 (1580)	0.27
	300	0.67 (0.21)		1097 (1399)		9429 (1496)	
Concentration NOx (ppm)	100	0.72 (0.19)	0.47	1119 (1404)	0.21	9063 (1719)	0.58
	300	0.68 (0.21)		757.1 (379.8)		9305 (1369)	
Pollutant order	N/S	0.75 (0.20)	0.053	729.5 (329.5)	0.15	8815 (1509)	0.098
	S/N	0.64 (0.19)		1146 (1408)		9553 (1516)	

Πίνακας 8 ANOVA για τις μεταβλητές μηχανικών ιδιοτήτων.

6. Συμπεράσματα

Τα βασικά ευρήματα συνοψίζονται ως εξής:

- Τα είδη των ρυπαντών που χρησιμοποιηθήκαν βρέθηκαν να είναι στατιστικά σημαντικά συσχετιζόμενα με τις μεταβλητές του χρώματος και τα θειούχα αέρια με τη μορφολογία.
- Η σειρά με την οποία εφαρμόστηκε η έκθεση σε NOx και SOx βρέθηκε στατιστικά σημαντικά συσχετιζόμενη με τις ιδιότητες χρώματος, τη σκληρότητα και τις μηχανικές ιδιότητες, δηλαδή τις οπτικές και τις μηχανικές ιδιότητες.
- Η υγρασία παρουσίασε στατιστικά σημαντική συσχέτιση με μεταβλητές που αφορούσαν στη σκληρότητα, τις μηχανικές ιδιότητες, τη χημική σταθερότητα και τη μορφολογία.
- Τέλος η διάρκεια ήταν στατιστικά σημαντική για τη χημική σταθερότητα και τη μορφολογία.

Στους Πίνακες 9 και 10 οι παράγοντες που βρέθηκαν στατιστικά σημαντικοί σε επίπεδο α=5% συμβολίζονται με Χ.

Συμπεραίνεται, επομένως, ότι ο πειραματικός σχεδιασμός της έρευνας που βασίζεται σε αξιοποίηση φυσικοχημικών δεδομένων και σε στατιστική επεξεργασία τους, αποτελεί ένα από τα πλέον αξιόπιστα εργαλεία για τη μελέτη θεμάτων συντήρησης πολιτιστικών τεκμηρίων, αφού συσχετίζει τους περιβαλλοντικούς παράγοντες (αίτιο) με τις παρατηρούμενες υποβαθμίσεις της ύλης (αποτέλεσμα) και δίνει τη δυνατότητα επανάληψης και ελέγχου της ερευνητικής διαδικασίας. Μια τέτοια προσέγγιση επιτρέπει τη συστηματική μελέτη επίδρασης διαφόρων περιβαλλοντικών παραγόντων στα πολιτιστικά τεκμήρια, μπορεί να οδηγήσει στην τεκμηρίωση λειτουργικών μοντέλων φθοράς αυτών και να αποδειχθεί χρήσιμο εργαλείο για τον επιτυχή σχεδιασμό και εφαρμογή πολιτικών προληπτικής συντήρησης πολιτιστικών αγαθών.

	Color properties			Gloss characterict (60o)			Chemical Stability Properties	
	L	a	b	Side A	Side B	Side C	Collagen antibodies	[Pro-Ser(OBzl)-Gly]n antibodies
Duration								X
Humidity								X
Sox		X						
Nox		X	X					
Pollutant Order	X	X	X					

Πίνακας 9 Οι παράγοντες που βρέθηκαν στατιστικά σημαντικοί για το οστό σε σχέση με τις μεταβλητές χρώματος, στιλπνότητας και χημικής σταθερότητας.

	Mechanical Properties			
	Vickers hardness	Mesh evaluation (mean vol. el.)	Strain Energy Density	Volume
Duration				
Humidity	X	X		
Sox				
Nox				
Pollutant Order	X	X		

Πίνακας 10 Οι παράγοντες που βρέθηκαν στατιστικά σημαντικοί για το οστό σε σχέση με τις μηχανικές μεταβλητές.

Ευχαριστίες

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GIS, REMOTE SENSING AND GEOSPATIAL MODELLING

TOWARDS A GIS RECONSTRUCTION OF THE AMMOUDARA COASTAL LANDSCAPE, INTEGRATING ARCHAEOLOGICAL EVIDENCE AND GEOMORPHOLOGICAL DATA

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Περίληψη/Abstract

Η παρούσα μελέτη εστιάζει στην κατασκευή Ψηφιακού Μοντέλου Εδάφους (DEM) ως βασικής συνιστώσας στην ανασύνθεση της πολιτισμικής βιογραφίας της παράκτιας περιοχής της Αμμουδάρας στη βόρεια-κεντρική Κρήτη και ως αφετηρίας στη διερεύνηση της αλληλεπίδρασης μεταξύ των φυσικών διεργασιών και του κοινωνικού της τοπίου. Για τη μελέτη των περιβαλλοντικών συνθηκών που επικρατούσαν στην Εποχή του Χαλκού και την κατασκευή του ψηφιακού μοντέλου εδάφους (DEM), η περιοχή εξετάστηκε γεωμορφολογικά και ιζηματολογικά, ενώ στο προτεινόμενο μοντέλο ενσωματώθηκαν αρχαιολογικές μαρτυρίες από σωστικές ανασκαφές και τυχαία ευρήματα.

The present study focuses on the construction of a Digital Elevation Model (DEM) as the basic component for the reconstruction of the cultural biography of the coastal area of Ammoudara in north-central Crete and the starting point in exploring the interplay between natural processes and the social landscape of the area. For the study of the environmental conditions in Bronze Age times and the construction of the DEM, the area was examined geomorphologically and sedimentologically, while archaeological evidence from rescue excavations and chance finds was also integrated in the proposed model.

Keywords: Sea Level Changes, Coastal Archaeology, Landscape Reconstruction, Digital Elevation Model (DEM), Minoan, Gazi, Ammoudara, Heraklion, Crete

1. Introduction

Understanding and modelling the geomorphological and the depositional processes, i.e. the transformation of the landscape in a diachronic perspective, is essential for exploring the cultural biography of a coastal area.

Coastal landscapes are dynamic landscapes, with their evolution to be strongly linked with waves and sea level variations. Their sediments are mainly formed in the Holocene and consist mostly of alternations of clay, peat beds and sand deposits.

There are several difficulties in studying the cultural landscape of coastal areas. These are principally related to their dynamic character in terms of environmental change. Wave and wind action result in processes like coastal erosion and the deposition of aeolian sediments, such as coastal dunes. These episodes in turn can generate new social relations and major changes as well.

A fundamental problem with reconstructions of this scale - which increases as one goes further back in time - is that they can be seriously compromised by the major changes often brought about by earth processes and climate change, which have erased or modified beyond recognition many physical features of the landscape as they existed at the time of human occupation (Bailey *et al.* 2011). This problem is particularly acute in regions of very active geological change (especially regions subject to active tectonics, periodic glaciation or sea-level change). Due to these difficulties, previous studies mainly focus on vegetation and climate reconstructions rather than the physical landscape (Field *et al.* 2007, Hughes *et al.* 2007).

This paper presents some preliminary results of an interdisciplinary collaboration focusing on the reconstruction of a Digital Elevation Model (DEM) of a specific coastal area in northern Crete during Bronze Age. Geomorphological and archaeological data are combined, as a starting point on exploring and understanding the environmental conditions and the social landscape of the region in the respective period.

2. Study area

The coastal zone of Ammoudara is the defined study area (Fig. 1), namely the northern part of Gazi-Ammoudara region, west of Heraklion, with a length of 6.1 km and width up to 60 m. The entire coastal area is shaped by significant geomorphological and tectonic processes as well as human activity (Fasoulas 2001).

On the landward side, the area is bordered by low altitude (<3 m.) sand dunes, which are located at distances between 30 and 60 m. from the coastline and range in height between 2.2 and 2.8 m. The inland part of the dune field area includes a low-lying region formed by fluvial illuviation. Moreover, the elevation of certain parts of this region falls very close to the sea level or even lower. A reef lies 80 m. offshore and parallel to its central and eastern part, having a total length close to 4 km., a mean width of about 35 m. and an average water depth of 1.5 m., whilst at its seaward side water depths exceeds 3 m. Its height above the seafloor exceeds 80 cm., reaching in places less than 0.5 m. from the sea surface.

Based on the presence or absence of the nearshore reef, the orientation of the coastline and the overall morphological and sedimentological characteristics, the coastal zone of Ammoudara can be subdivided in three sections (Alexandrakis *et al.* 2006).

Figure 1 Study area (Image source: Esri, GeoEye, EarthStar Georgafics CNES/Airbus DS, USDA, USGS, AEX, Getmaping, Aerogrid, IGN, IGP and GIS User Community, 2016).

The western section, 2500 m. in length, begins at the west end of the beach and ends to the east of the mouth of River Gazanos, including the mouth of Almiros, where the reef recesses. Along the coastline, there is a typical beachrock formation. The middle section, which begins 600 m. eastward of the mouth of Gazanos, extends 2300 m. in length and ends at the mouth of the River Xiropotamos; in this section, the reef is present and parallel to the coastline. The sand dunes are at an average distance of 50 m. from the coastline and have an average height of 2 m. To the East of the Gazanos river mouth, the reef appears at an average distance of 30 m. from the coastline. It is parallel to the shore and disappears at the River Xiropotamos mouth area, where, for a distance of about 200 m. the surface of the reef is planar, dipping seawards by 3^o - 4^o. Its width ranges from 15 m. up to 50 m. and it is located on average 0.7 m. below the sea surface (minimum depth 0.5 m.). Furthermore, its surface is characterised by a large number of runnels, potholes and grooves, whilst the lower part is cross-bedded, resembling the cross bedding of coastal aeolian formations. The grooves are similar to the ones formed in typical beachrock formations by the retrograde movement of water on top of them at the beach face. The eastern section lies between the mouth of the River Xiropotamos and the mouth of the River Giofiros, which is the natural east end of the beach; this section has a length of 1100 m. and the reef is present in the nearshore zone. In this area, the reefs surface is almost level, being in places as little as 0.3 m. below the sea surface. At its east end, the reef presents large cracks, whilst the bathymetry at its seaward side is characterised by a 1 - 1.5 m. step (Alexandrakis *et al.* 2006).

Overall, the characteristics of the submerged beachrock in front of Ammoudara indicate a past shoreline, which retreated approximately 60 m., and is associated with a relative sea level rise (Alexandrakis *et al.*, 2013).

The coastal area of the Gazi-Ammoudara region, west of the palatial centre of Knossos and not far from the Psiloritis region and the administrative Minoan centre of Tylissos, is archaeologically regarded among the most poorly investigated areas. This gap in the archaeological research provides bias in regional and inter-regional archaeological interpretations and affects our understanding of the political, social and economic networks in north-central Crete. Consequently, for heritage management this gap is even more pronounced, since the lack of data and limited knowledge about existing archaeological sites and features implies difficulties in implementing effective strategies for their preservation.

2.a Tectonics / sea level changes

The analysis of the tectonic faults in the area has shown that from the Middle Miocene until present, the tectonic development of the Heraklion basin has been mainly the result of successive extensional periods that generated at least three faults. The first, consisting of east - west trending faults, was probably initiated in the Early Miocene. However, the most extensive activation of these faults took place during the Middle/Late Miocene until the early Messinian as a result of the southwards roll-back of the subduction zone. The established north-south extensional regime created the first east-west trending basins in the area of Crete (Fasoulas 2001). Another more recent event in Ammoudara was the AD 365 earthquake, when vertical movements in the area reached -1 m. (Fig. 2).

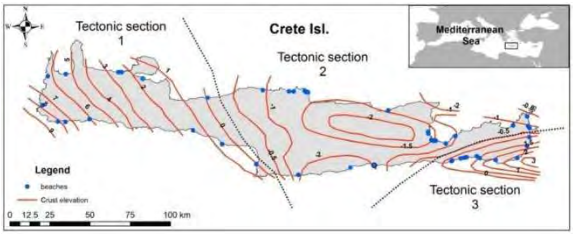

Figure 2 Tectonic uplift after the AD 365 Earthquake (modified from Stiros 2010).

Sea level in the Aegean Sea in the last glacial period (20–21 ka BP) was at 120 m. to 105 m. lower than today (Pirazzoli 1991, Lambeck & Bard 2000). From 11500 to 6000 BP there was a quick rise, due to glacial/eustatic factors, and sea level reached 5±1 m. lower than today. In the last 5000 years, sea level rise followed a steady rate of approximately 0.9 mm./year. 2000 BP the sea level was found 2.5 m. lower than its present value (Lambeck 1996, Fouache *et al.* 2005, Vouvalidis *et al.* 2005).

Moreover, the eruption of Santorini in the Late Bronze Age resulted in tsunami waves, based on the evidence of tsunami deposits along coastal areas of Greece (McCoy & Heiken 2000, Manning *et al.* 2006, Sigurdsson *et al.* 2006). Numerical models have shown that tsunami wave amplitudes were significant with inland inundation up to 200 m. along the coast of Crete (Bruins *et al.* 2008). Additionally, evidence from the AD 365 earthquake, the largest known seismic event in the Eastern Mediterranean, support the idea that the respective tsunami reached not only the NW part of Crete, but also affected the coastal areas in Heraklion (Flouri *et al.* 2013).

2.b Archaeological overview

The archaeological importance of the region has been documented by early scholars, such as I. Hatzidakis (1918) and A. Evans (1928). Although several archaeological remains were destroyed by natural processes and modern human activity (agriculture, grazing and construction), evidence from rescue excavations, surface remains and chance finds dating from the Neolithic to the Ottoman period were found in many parts of the area, suggesting intensive patterns of habitation and other human activity (Fig. 3).

However, the only excavation in the coastal zone was carried out in the late 1970s and revealed a building, which was only partially excavated (Fig. 4). It seems that it was a domestic unit, which most likely belonged to an extensive Neopalatial (MM III - LM IA) settlement that was part of the wider social contact network in the northern coastal zone of Minoan Crete. Pottery from the excavation is dated predominately to MM III - LM IA (Fig. 5), though it includes Pre- and Post-palatial sherds (Vallianou 1979, Athanasaki 2015).

Figure 3 Minoan sites, location of Minoan building (settlement) and the position of the research drill. (Image source: Esri, GeoEye, EarthStar Georgafics CNES/Airbus DS, USDA, USGS, AEX, Getmaping, Aerogrid, IGN, IGP and GIS User Community, 2016).

Figure 4 Area and archival depiction of the Minoan settlement (Photos by Ephorate of Antiquities of Heraklion (EphAH).

Figure 5 Pottery and painted plaster fragments from the excavation of 1979 (MMIII-LMIA) (Photos by Katerina Athanasaki - drawings by P. Stefanaki).

3. Materials and Methods

The first step towards the DEM reconstruction of the study area was the implementation of the geomorphological and sedimentological mapping. For the geomorphological mapping, topographic diagrams from the Hellenic Army Geographical Service and GeoEye satellite images were used. The morphodynamic measurements, which included beach elevations and slopes, were taken with the use of a D-GPS, whilst depth soundings were acquired with the use of a single beam echo-sounder reaching 5 m. depth within water. Furthermore, surficial sediment samples were collected along the profiles and analysed according to Folk's (1974) procedure. Finally, a research drill reaching 8 m. below surface was made to determine the deposition environment of the coastal sediments (its location in shown in Fig. 3). The proposed DEM was generated using a combination of archaeological evidence, tectonic data and a detailed geomorphological and sedimentological mapping of the modern landscape.

4. Results

4.a Geomorphology

The overall morphological and sedimentological characteristics of the reef are very similar to those of the present beachrock formations in the western part of the Ammoudara beach. Evidence for the formation of the reef along a former shoreline as a beach rock contain: (i) its position parallel to the present shoreline; (ii) its morphological characteristics, such as its width, thickness, upper surface slope and morphology (e.g. runnels); (iii) its absence in front of the river mouth areas; (iv) the material of its upper layer, which is similar to modern beach zone material; (v) the cross-bedding of its lower part, which is analogous to aeolian coastal formations; (vi) the presence of freshwater inputs along the beach zone available for mixing with seawater (e.g. karstic source of Almiros) and (vii) its western prolongation, which coincides with the modern beachrock formations found on the current beach face.

4.b Stratigraphy

The stratigraphy of the research drill indicated that, the dune system in the area is very old. Sedimentological finds between 1.8 m. and 8 m. depth consist of sandy and gravely sandy deposits, which are typical coastal dune deposits. Few different layers were recognised, e.g. a layer between 3.5 and 3.7 m. with slightly coarse material and the presence of pumice. Also, at a depth of 6.5 m. (4.2 m. from the surface of the sea) a small sherd was retrieved (Fig. 6).

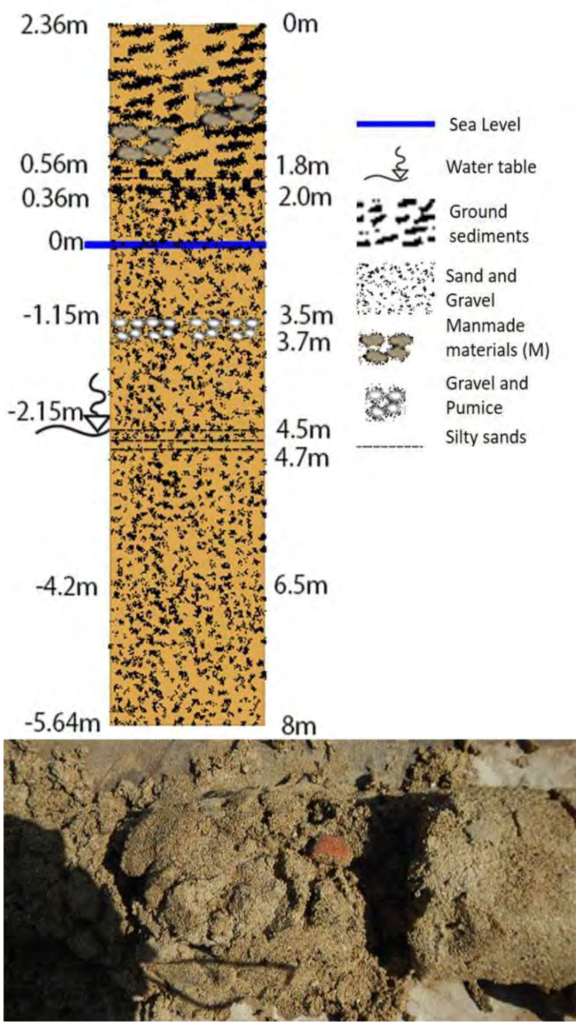

Figure 6 Stratigraphic column and small ceramic remnant found within the drill sediment.

4.c Coastal evolution

As regards the dune system area, the conceptual model of Alexandrakis *et al.* (2013) was considered (Fig. 7). In this model, it is stated that, there were multiple lines of sand dunes; the older being quite stable and hosting an alluvial area behind them. As the sea level rose, younger dunes were eroded and stable aeolian deposits were brought to the surface. Concurrently, a beachrock formation was developing in the coastline. As the sea level began to rise, coastal erosion removed sediments from the beach and, eventually, the beachrock was separated from the beach, submerged and formed the present-day reef. In the areas of Giofiros and Almiros the low topographic relief and muddy sediments act as indicators of a potential lagoon system behind the dune field.

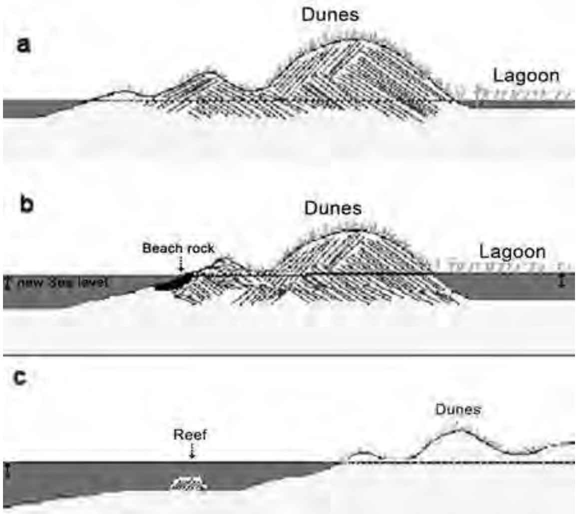

Figure 7 Coastal evolution model (modified from Alexandrakis *et al.* 2013).

4.d The Digital Elevation Model

An initial DEM was generated by inputting the tectonic movements and the sea level rise rates for the last 4000 years and combining these with archaeological data from the same area. The proposed DEM can be used as the basis for future more detailed reconstructions in order to understand the landscape archaeology of the area (Ashmore 2004). The Ammoudara beach zone appears in the reconstructed DEM wider and the dune field more developed (Fig. 8).

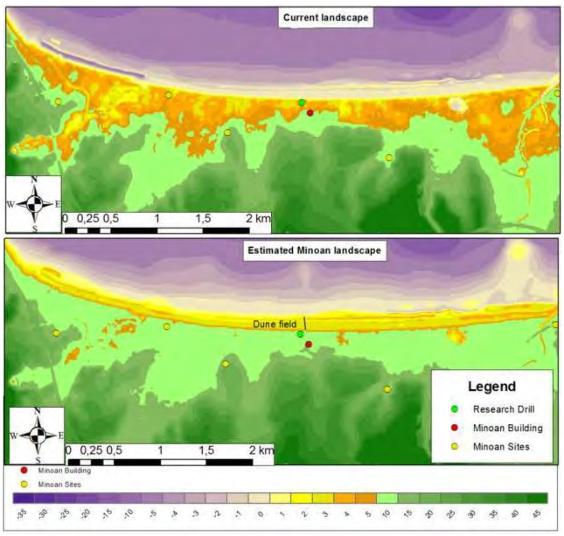

Figure 8 Current and reconstructed DEM.

The model indicates that the beach area was wider and longer. The area behind the dune system had higher altitude, while the area where the Minoan building was found was at a distance from the dune system. The accuracy of the reconstructed DEM can be supported by the findings of the research drill, in which the entire 8 m. depth column corresponds to dune field sediments.

5. Conclusions-Future work

The shore-parallel reef in the Ammoudara coastal zone is a submerged beachrock that was formed during the upper Holocene. Its current position, about 0.5 m. below sea level, indicates a relative sea level rise of more than 0.5 m; the latter has caused a coastline retreat of approximately 60 m. At present, the beach zone of Ammoudara seems to be stable and in morphodynamic equilibrium with the nearshore hydrodynamic conditions. The reef acts as a natural submerged breakwater that protects the shore from erosion by reducing the incoming wave energy and inducing intense wave breaking farther from the shoreline.

Overall, the landscape reconstruction suggests that geomorphologically the area was very different in the Bronze Age. Based on the archaeological and geomorphological finds, alluvial plane sediments seem to have been appropriate for agriculture, while the location of shoreline is indicated approximately 200 m. from its current position.

Work in progress and future research include more detailed paleoenvironmental studies, research drills in further locations to achieve a more precise idea of the stratigraphy, supplementary correlations with archaeological sites and features, as well as detailed studies and reappraisal of old excavation data. Using a multi-disciplinary approach several questions can be investigated such as:

- How has sea-level change influenced human populations and what was the effect on the archaeological record?
- How can natural phenomena and processes affect human behaviour and contribute to cultural change?
- In what way can specific natural disasters like the tsunami caused by the Santorini eruption be related with the historical events of the Late Minoan IA/B?
- Finally, what types of interaction between Bronze Age people and the coastal landscape are evident in the area? Can they be considered a result of continuous and discontinuous multi-scalar natural and cultural processes?

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GEOINFORMATIC APPROACHES TO ASSESS THE LANDFORM CHARACTERISTICS OF MINOAN SETTLEMENTS AND CHARACTERISE THE WATER MANAGEMENT PLANNING IN BRONZE AGE CRETE

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Περίληψη/Abstract

Ο προσδιορισμός της γεωμορφολογίας παίζει σημαντικό ρόλο στην αρχαιολογική έρευνα του τοπίου. Διάφοροι τύποι γεωμορφών μπορούν να διακριθούν από χαρακτηριστικά γεωμορφολογικά στοιχεία που απεικονίζουν τον περίγυρο του οικισμού και να αξιολογηθεί η γεωγραφική τους σημασία όσον αφορά την ικανότητά τους να διατηρήσουν έναν πληθυσμό. Διάφορες προσεγγίσεις γεωπληροφορικής μελετούνται, χρησιμοποιώντας τη δωρεάν διάθεση του ψηφιακού μοντέλου ανύψωσης ASTER G-DEM. Οι θέσεις των αρχαιολογικών οικισμών και ο χαρακτηρισμός των κυρίαρχων γεωμορφομετρικών στοιχείων του τοπίου μπορεί να αποκαλύψουν πληροφορίες για την ανάπτυξη των οικισμών και να παρέχουν μια καλύτερη κατανόηση της ανθρώπινης συμπεριφοράς, όσον αφορά τα χαρακτηριστικά του τοπίου με την πάροδο του χρόνου, όπως η διαχείριση των υδάτων. Η μελέτη αυτή έχει ως στόχο να αξιολογήσει τις καλύτερες διαδρομές για τους υδάτινους πόρους που καταφθάνουν στους μεγαλύτερους οικισμούς, εφαρμόζοντας τεχνικές ολοκληρωμένων πολλαπλών κριτήριων ανάλυσης αποφάσεων (MCDA) και τεχνικές ανάλυσης του ελαχίστου κόστους διαδρομής (LCPA) με τη χρήση γεωγραφικών συστημάτων πληροφοριών (ΓΣΠ). Μια τέτοια προσέγγιση αποδεικνύεται ως ένα πολύτιμο εργαλείο για τους αρχαιολόγους προκειμένου να προσδιορίσουν και να αξιολογήσουν τον σχεδιασμό της διαχείρισης των υδάτων στην αρχαιότητα.

The determination of geomorphology plays an important role in archaeological landscape research. Several landform types can be distinguished by characteristic geomorphic attributes that portray the surrounding landscape of a settlement and evaluate its geographical importance in terms of its ability to sustain a population. Various geoinformatic approaches are acknowledged, by using the free available ASTER G-DEM. The locations of archaeological settlements and the characterisation of the dominant surrounding landscape geomorphometrics can reveal insights into the development of settlements and provide a better understanding of human behaviour, with regard to the landscape characteristics over time, such as the water management. This study aims to assess the best routes for water resources reaching the major settlements, by using integrated Multi-Criteria Decision Analysis (MCDA) and Least-Cost Path Analysis (LCPA) approaches in GIS. Such an approach proves to be a valuable tool for archaeologists to determine and evaluate the water management planning in ancient periods.

Keywords: Bronze Age Crete, Landform Classification, Water Management, Multi-criteria Decision Analysis, Least Cost Path Analysis

Introduction

The Earth's surface consists of various physical properties that influence local topography and indirectly influence human behaviour in terms of habitation patterns. In order to characterise the underlying landscape in the location of a settlement, a number of landform types can be distinguished using geoinformatic approaches to evaluate different geomorphological characteristics. The information that can be derived provides significant information regarding the topographic position of archaeological settlements.

In recent years due to improvements in computing capabilities and software functionality, geoinformatic approaches can provide a useful tool for decision makers managing natural resources, human resources and archaeo-heritage resources. Initially, Geographical Information Systems (GIS) techniques are acknowledged in order to determine the landform types and the geomorphometric characteristics. A number of geomorphometric variables (e.g. drainage density, elevation relief etc), extracted from the ASTER Global Digital Elevation Model (ASTER G-DEM) are evaluated through various algorithms incorporated into free open source GIS software. Moreover, the landscape can be classified into morphological classes based on the topography by adopting the difference from mean elevation (*DIFF*) analysis (Gallant & Wilson 2000). The positions of archaeological settlements and the characterisation of the dominant surrounding landscape geomorphometrics can reveal insights into the development of settlements and provide a better understanding of human behaviour with regard to the landscape characteristics over time, such as the water management.

During the Bronze Age period, advanced water management techniques were practiced in several settlements around Crete. Various water resources, such as wells, springs, cisterns and aqueducts were supplying the settlements according to local conditions in terms of geomorphology. The Minoans were forced by nature to develop advanced hydraulic systems for transporting water, due to the mountainous terrain, especially in regions with water scarcity due to the dry climate and the distance of settlements from major water bodies (Angelakis *et al.* 2005). Finding the routes through which the water resources were reaching and supplying the major settlements is a challenging aspect with GIS being a powerful tool in this direction.

This study aims at the analysis of best routes for water resources to reach major settlements, by using integrated Multi-Criteria Decision Analysis (MCDA) and Least-Cost Path Analysis (LCPA) approaches in GIS (Herzog 2010, Kathuo & Mubea 2013). The derived information in conjunction with hydrolithology is combined within an MCDA in order to highlight those landscape characteristics being advantageous in water management planning. The outcome from the MCDA analysis provides the cost surface in order to plan the most suitable route for water resources by using LCPA and considering several criteria in the analysis (such as springs, wells, aqueducts etc.). By assessing the landscape impact to past human occupation and exploration of water resources routes, the MCDA and LCPA approaches prove their applicability towards the evaluation of water management in ancient periods as well as the potential discovery of new archaeological features.

1. Methods and Results

The landform classification was based on the difference from mean elevation (DIFF) analysis (Jenness 2005) using as an input dataset the free available ASTER Global DEM (G-DEM: 30 m. spatial resolution) and the allocated archaeological sites for each Minoan period respectively, as recorded by the archaeological surveys of Hayden *et al.* (2004), Watrous *et al.* (2004) and Haggis *et al.* (2005).

DIFF (z_0-z) measures the relative topographic position of the central point as the difference between the elevation of this central point and the mean elevation within a predetermined neighbourhood (Gallant & Wilson 2000). This index can be used to classify the landscape into morphological classes (Jenness 2005).

The *DIFF* based landform classification can produce 10 landform classes: streams, mid-slope drainages, local ridges, valleys, plains, foot slopes, upper slopes, upland drainage, mid-slope ridges and high ridges (Tagil & Jenness 2008) (Fig. 1). Usually, two neighbourhood sizes (in this study 100 m. and 600 m.) are combined to offer detailed geomorphological information through the discrimination of complex landscape features, as a single neighbourhood size provides less information about the general shape of the landscape (Tagil & Jenness 2008).

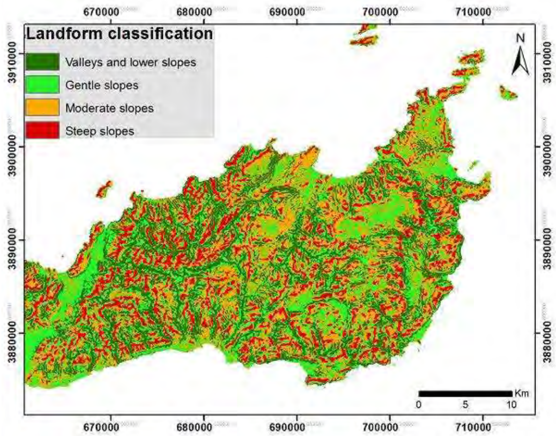

Figure 1 The landform classification based on *DIFF* (eastern Crete), as extracted from ASTER G-DEM.

In this study, the various calculated geomorphological derivatives (Table 1), such as amplitude of relief (Ar), topographic terrain wetness (TWI), slope gradient (Sg), drainage density (Dd), stream frequency (Fu), elevation relief (Er), stream length gradient (SL), surface area/ratio (SAR), dissection index (Di) were used in an MCDA model to provide the morphometric classification map (Fig. 2). In conjunction with the landform and morphometric classifications, a hydrolithological map was acknowledged in the MCDA procedure in order to contribute the levels of permeability and their impact to water flow infiltration capacity (Fig. 3). All these mapping information contribute to the creation of the final cost surface raster, used as an input in the LCPA procedure, by evaluating the assemblage of the various derived thematic maps (Fig. 4-5).

Indices	**Formula**	**Description**	**Bibliography**
Amplitude relief (*Ar*)	***Ar*= z(max)- z(min),** where z is the elevation within unit areas of 1 km^2	The spatial distribution of the maximum difference in elevation within unit areas of 1 km^2. A parameter that can be used for the statistically orographic configuration of the study area in order to determine fluvial erosion. Provides information associated with recent vertical displacements of uplifted or subsidence blocks.	Ciccacci *et al.* 1988
Stream length gradient (*SL*)	$SL = (\Delta H / \Delta L) \times L$, where ΔH is the height increase, ΔL the horizontal distance corresponding in each case to ΔH, and L the accumulated length from the starting point to the middle point of the interval.	The ratio of the change in elevation of the reach to the length of the reach multiplied with the total length of the channel from the point of interest where the index is being calculated. Abrupt changes in the gradient of river can be associated with active tectonics.	Hack 1973
Drainage density (*Dd*)	$Dd = \Sigma L / A$, where ΣL is the total length of all the ordered streams and *A* is the area of the basin.	The ratio of the total stream length to the area of the basin. The drainage density reveals information regarding surface runoff potential, ground surface steepness, the degree of landscape dissection, rock permeability and resistance to erosion.	Horton 1945
Stream frequency (*Fu*)	$Fu = N / A$, where N is the total number of stream segments and A is the area of the basin.	The ratio of the total number of the stream segments to the area of the basin. The values of stream frequency indicate the degree of slope steepness, rock permeability and surface runoff.	Horton 1945
Slope gradient (*S*)	$\text{Slope} = \sqrt{(G^2 + H^2)}$, where G is the east-to-west gradient and H is the north-to-south gradient	Slope gradient algorithm shows maximum slope steepness, indicating the change in elevation between each cell and its neighbors, thus allowing relationships in basin morphometry to be determined.	Evans 1979
Topographic Wetness Index (*TWI*)	***TWI*= ln (*As* / tan*b*),** where *As* is the upslope contributing area and tan*b* is the local slope.	Determines the spatial distribution of soil moisture and surface saturation with regard to the influence of topography, based on digital elevation models (DEMs). Narrow V-shaped valleys can be determined as a characteristic aspect of active tectonics.	Beven & Kirkby1979
Elevation relief (*Er*)	$SRR = (z(mean) - z(min)) / (z(max) - z(min))$, where *z* is the elevation.	Describes rugosity in a continuous raster surface within a specified window.	Pike & Wilson 1971
Surface area/ratio (*SAR*)	$\text{Surface area} = c^2 / \cos(S(\pi \setminus 180))$, where *c* is the cell size and *S* is the slope in degrees.	Reflect the surface area and (surface area) / (planimetric area) ratio for the land area contained within that cell's boundaries. Surface Ratio provides a useful index of topographic roughness and convolutedness, while Surface Area gives a more realistic estimate of the land area available than you can get from the simple planimetric area.	Hobson 1972
Dissection index (*Di*)	$D = z(max) / (z(max) - z(min))$, where *z* is the elevation.	Dissection describes dissection in a continuous raster surface within rectangular or circular window. It is the ratio between the absolute relief and relative relief. It is an important geomorphological tool for estimating vertical balance of erosion. It is useful in the study of the terrain, the dynamics and the stages of landscape evolution.	Evans,1972

Table 1: Geomorphometric indices formulas and description.

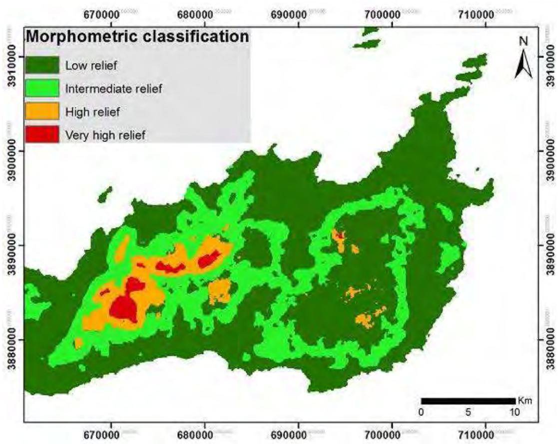

Figure 2 The morphometric classification based on various geomorphometric variables (eastern Crete), as extracted from ASTER G-DEM.

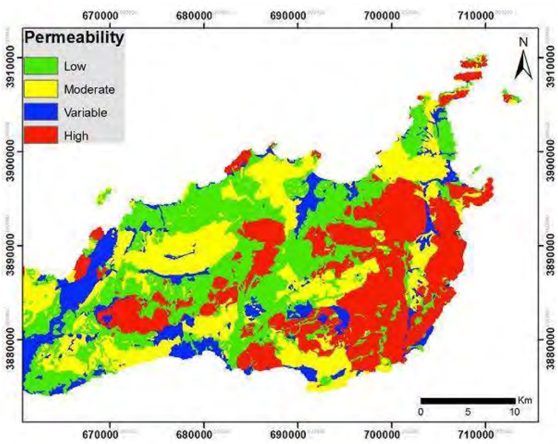

Figure 3 The permeability levels of the hydrolithological formations (eastern Crete).

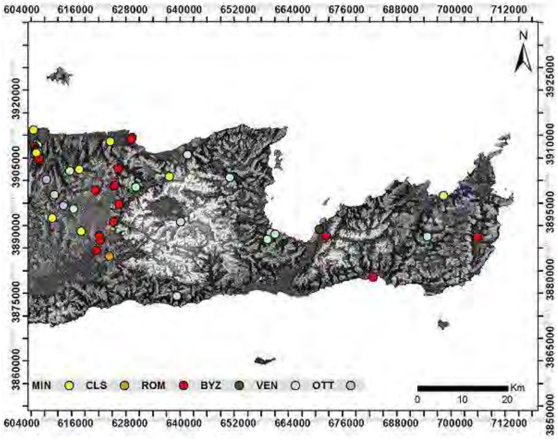

Figure 4 The various water resources through diverse historical periods, overlaid in cost surface raster.

The least cost path between two points is the path of least resistance or lowest cost, where cost is a function of time or other user-defined factors. The neighbours of a raster cell are evaluated with the generated path moving from one cell to another following the smallest accumulated or cost value. This process is repeated multiple times until source and destination are connected. The cost surface raster is based on the contribution of the landform classification by 55%, the geomorphometric classification by 34% and the hydrolithological information by 11%. This indicates that the higher contribution is provided by the landform classification, which was derived by the characterisation of the topography based on two neighbourhood sizes windows (100 m. and 600 m.). This range used in the neighbourhood sizes windows is larger than the 30 m. spatial resolution of the ASTER G-DEM.

As a result, the prior topography is generalised in more than one raster cell and minimises any irregularities or anomalies in the LCPA route. In a GIS environment, least cost path analysis is the application of spatial tools to determine the lowest cost path between two or more termination points. LCPA has been employed in the past in the analysis of Roman aqueduct routes (Roldan *et al.* 1999, Lagostena & Zuleta 2009). Due to their specific characteristics which combine a constructed trace and a water flow, aqueducts do not obey cultural, topographic or hydrologic conditionings alone, but a combination of all these. For that reason, several characteristics of aqueducts have to be taken into account when modelling their route. Firstly, they only flow in one direction so anisotropic models are to be preferred. Secondly, following a downhill route, gradient being constant, excessive downward slope is not supported by unpressurised conduits. Finally, they can also incorporate engineering works such as cascades, tunnels, siphons or arcades, which allow them - to a certain degree - to overcome topographic restraints.

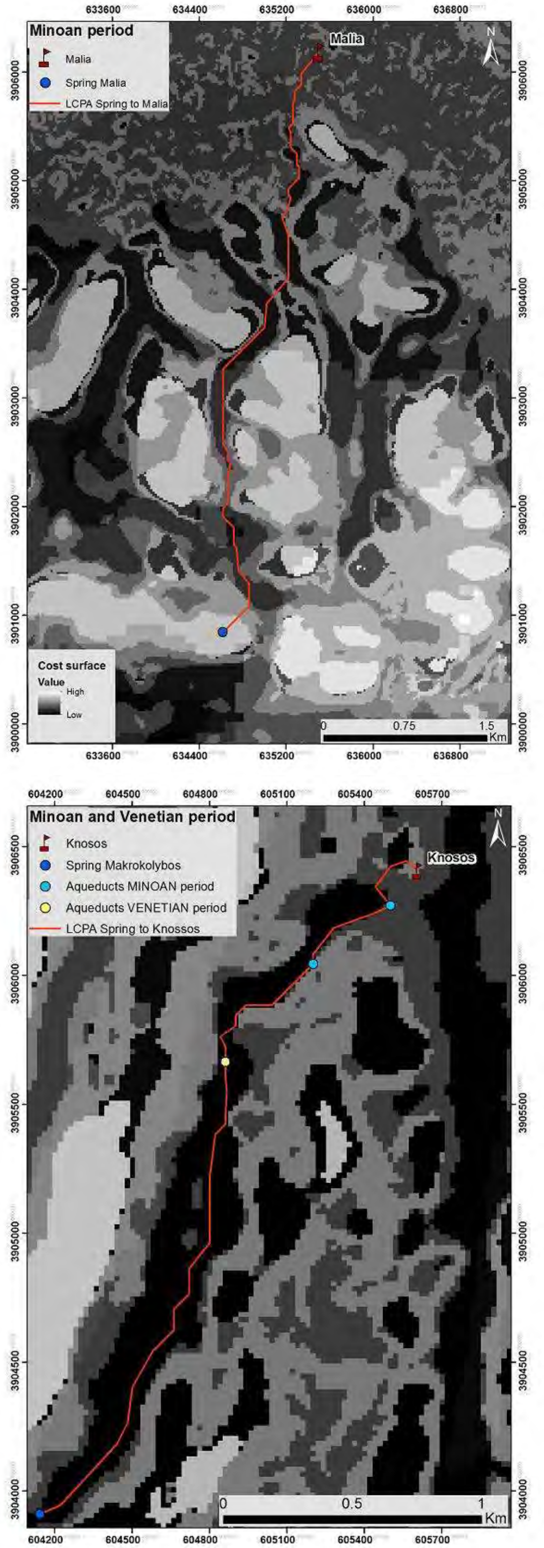

Figure 5 LCPA for Malia with the route from the water resource (spring) to the settlement (Malia), overlaid in the cost surface raster (top); LCPA for Knossos with the route from the water resource (Makrokolybos spring) to the settlement (Knossos), overlaid in the cost surface raster (bottom).

The development of LCPA analyses based on cost surfaces has been acknowledged as a useful methodological approach in the archaeological analysis of movement. The locations suggested by the different water resources (e.g. springs, wells) associated with the aqueduct's traces are essential in modelling the most appropriate route (Fig. 4-5). The model will be applied and refined using the archaeological evidence known for the aqueducts. The cost surface raster comprised the source input to perform the LCPA procedure. It's common in the literature to use only the slope gradient as the input dataset, but this study makes use of a various number of geomorphological derivatives to enhance geomorphological, tectonic and hydrological aspects, which in conjunction with landform types and permeability provide a much more enriched and ideal cost surface raster input dataset.

Conclusions

This study examined the importance of geomorphological attributes that portray the surrounding landscape of a settlement in order to evaluate its geographical position and the degree of its ability to sustain a population. Various geoinformatic approaches using the free available ASTER G-DEM were acknowledged herein, revealing important information regarding the development of settlements. In addition, they provided a better understanding of human behaviour, with regard to the landscape characteristics over time, such as the water management.

Initially, the derived landform types surrounding the individual settlements, for the successive Bronze Age subperiods, provided two main highlights of the distributed settlements location. Firstly, the high increase on valleys and plains; secondly, the high decrease on open slopes and mid-slope ridges. These observations were examined statistically indicating the tendency of population movement through the years from higher elevated areas during the Early Minoan period to lower areas in the following periods. This can be interpreted as a population trend, after the Early Minoan period, connected to better accessibility to arable land and water resources.

In order for the settlements to remain active through the years, the accessibility and exploitation of the nearby water resources was vital. This research aimed, by using the LCPA approach in GIS, to assess the routes that existed for the various water resources (e.g. springs, aqueducts) to reach the major settlements. The cost surface dataset that was created through the MCDA procedure contained diverse morphological, hydrolithological and geological information. Such valuable individual information contributed in the improvement of the cost surface dataset for water resources routes identification, in comparison to previous studies where minimum information, such as slope, was acknowledged as the only cost surface factor. Various routes linking water resources and settlements were identified in this study helping towards the reconstruction of the water management through the centuries (e.g. Bronze Age, Roman, Byzantine). Water resources routes identified in this study were overlapping with previously reconstructed routes, which were based on extensive archaeological studies and in-situ observations. This indicates that the methodological framework of this study can provide an alternative low cost tool for archaeologists to examine the water management of archaeological sites through the years.

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SPECIES DISTRIBUTION MODELS FOR THE INVESTIGATION OF NEOLITHIC SITES IN THE TAVOLIERE PLAIN (SOUTHERN ITALY)

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Περίληψη/Abstract

Η μελέτη της κατανομής των αρχαιολογικών θέσεων στο τοπίο αποτελεί ουσιαστικό παράγοντα ως προς τη στρατηγική προστασίας της πολιτιστικής κληρονομιάς και την αποτελεσματική διαχείριση της επικινδυνότητας των αρχαιολογικών μνημείων και θέσεων από περιβαλλοντικούς και ανθρωπογενείς παράγοντες. Η διερεύνηση πιθανολογικών μοντέλων κατανομής και δεδομένων από δορυφορικές εικόνες μπορούν να συνεισφέρουν προς την κατεύθυνση αυτή. Δύο μοντέλα πρόβλεψης – το πρώτο που βασίζεται σε πολυ-παραμετρικές χωρικές αναλύσεις σε περιβάλλον GIS και το δεύτερο που κάνει χρήση του πιθανολογικού μοντέλου της μέγιστης Εντροπίας (MaxEnt) – αξιολογήθηκαν μέσω της εφαρμογής τους με μία επαγωγική προσέγγιση στην πεδιάδα Tavoliere της Νότιας Ιταλίας, λαμβάνοντας υπόψη την παρουσία γνωστών αρχαιολογικών θέσεων. Η συγκεκριμένη διαδικασία έκανε χρήση τοπογραφικών, γεωμορφολογικών και περιβαλλοντικών πληροφοριών που εξήχθησαν από δορυφορικές εικόνες. Τα αποτελέσματα της έρευνας υποδεικνύουν την καλύτερη απόδοση του μοντέλου MaxEnt, ενώ η ανάλυση των κυρίων συνιστωσών (PCA) με βάση το κριτήριο AIC (Akaike's Information Criterion) εμφανίζεται καθοριστική για την επιλογή των περιβαλλοντικών παραμέτρων.

Cultural heritage protection policies and the efficient management of archaeological risk impact inherent in infrastructural planning require the study of the distribution of archaeological features in present landscapes. This can benefit from the combined use of probability distribution models and remote sensing data. Two predictive models (GIS-based multiparametric spatial analysis and MaxEnt) were compared and assessed with an inductive approach in a well-investigated area of the Tavoliere Plain (Southern Italy) based on data about known sites. Topographic, geomorphological and remote sensing derived environmental variables were employed. The MaxEnt model provided the best performance. Model selection (Akaike's Information Criterion) indicated spatial PCA as a viable means for the choice of environmental variables.

Keywords: Archaeology, GIS Multiparametric Spatial Analysis, Maximum Entropy (MaxEnt), Neolithic, Predictive Models, Remote Sensing, Spatial PCA

Introduction

The use of predictive models for the analysis of the distribution of archaeological sites is considered by several authors (e.g. Fernandes *et al*. 2011, Ford *et al*. 2009) under different modelling approaches and assumptions (i.e. deductive and inductive - Kamermans 2006), either starting from an *a-priori* knowledge of historical aspects and using presence sites as reference for validation or correlating site locations with the environmental features. Multiparametric spatial analyses (MPSA) in GIS have been applied for the prediction of settlement distribution (e.g. Alexakis *et al*. 2011).

More recently, approaches generally employed in ecological investigations for modelling the probability of species distribution (SDMs) have been extended to archaeological issues. The MaxEnt model, considered one of the most efficient and robust among such models (Elith *et al*. 2011), has been applied within an archaeological context under both the deductive (e.g. Franklin *et al*. 2015) and inductive approach (e.g. Ullah 2011, Galletti *et al*. 2013).

The objective of this work is to compare and assess two inductive models, GIS-MPSA (Noviello *et al*. 2015) and MaxEnt to investigate the distribution of Neolithic sites in the Tavoliere Plain (e.g. Jones 1987, Ciminale *et al*. 2007).

1. Methodology

A representative area of the Tavoliere Plain (Puglia) was considered (538.26 km^2; coordinates of the square vertices: 41°19'33.57"N - 15°36'29.13"E, 41°19'26.63"N - 15°54'7.80"E, 41°19'26.63"N - 15°54'7.80"E, 41° 7'40.51"N - 15°36'22.47"E; Fig. 1), containing 120 known Neolithic sites regularly distributed on a square regular grid (1.5 km x 1.5 km). The sites included those identified by either remote sensing (49), specifically geophysical prospections and cropmark examination on satellite/aerial images (e.g. Gallo *et al*. 2009; Noviello *et al*. 2013), or archaeological identification methods (71) (Barbanente *et al*. 2010).

Thirteen environmental variables were considered as in Noviello *et al*. (2015); namely attributes providing archaeologists-geophysicists with cues on former habitation in the region:

- Topographic features (T): altitude, slope and aspect (8 m x 8 m pixel resolution and 1 m altitude accuracy);
- Geomorphological features (G): river network, quarries, and river morphology nominal scale 1:25000; Proximity maps to these features were derived.
- Vegetation indices (VI): ARVI, NDVI, Green NDVI, SAVI, MSAVI, MSR, computed from a Landsat 8 image (spatial resolution 30 m x 30 m, 11 bands spectral resolution) acquired on 20 June 2013.

The GIS-MPSA model was implemented following the main steps described in Noviello *et al.* (2015):

1. Reclassification of environmental maps on the basis of weights proportional to the site frequency in predefined classes of values.
2. Assignment of importance weights to the three environmental categories (with equal variables weights within each category).

The model was implemented at a map resolution of 200 m, as this spatial scale reflects the environmental conditions of the average extent (34246 m^2 in approximation) of the polygons outlining each settlement. The 200 m resolution map was obtained by the aggregation of the pixel values of reclassified environmental variables maps (2 m x 2 m).

Weights were assigned to categories according to the analytic hierarchy process AHP (Saaty & Peniwati 2007). A series of MaxEnt models was built considering different sets of environmental variables to avoid collinearity effects. Controlling for collinearity among environmental variables in MaxEnt is crucial to avoid the allocation of greater importance to two or more highly correlated variables, which can affect the results. Collinearity assessment leading to the selection of the variables was performed by means of two alternative approaches: Pearson's correlation and a spatial variant of PCA (Johnston 1978) for the analysis of raster data (Jensen 2015). For the selection of the "best MaxEnt model", the Akaike Information Criterion (Akaike 1973) with a correction for small sample size (AICc) (Burnham & Anderson 2002) and Akaike weights (wAICc Wagenmakers & Farrell 2004) were applied.

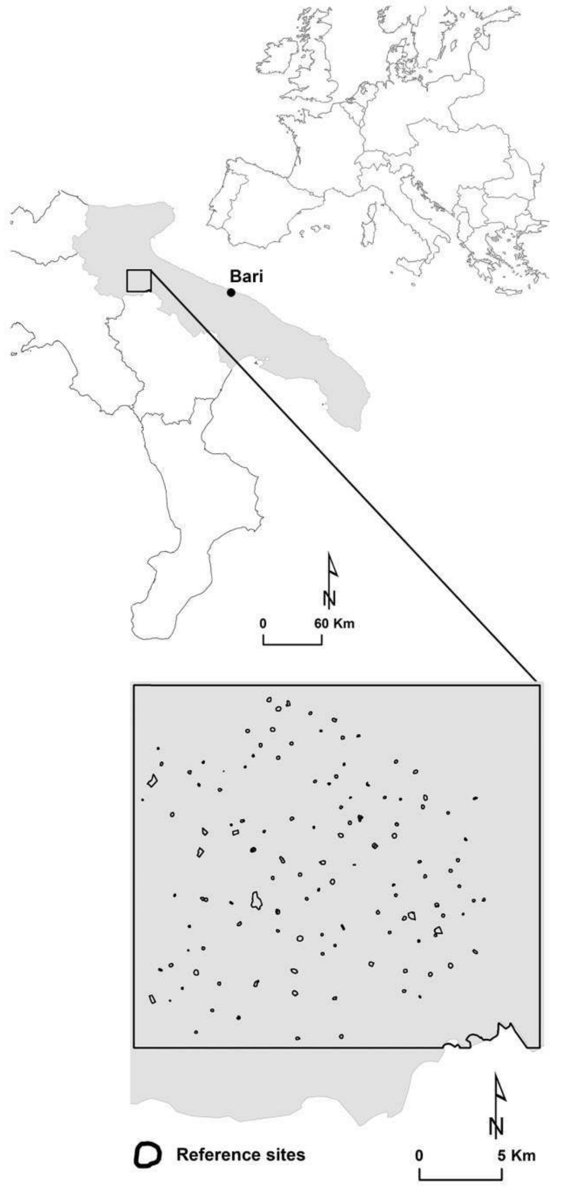

Figure 1 Study area.

To assess and compare the predictive power of the GIS-MPSA model and of the "best MaxEnt model", the Receiver Operating Characteristic/Area Under the Curve (ROC/AUC) analysis (Fielding and Bell 1997) was performed, by means of the DIVA-GIS software modelling evaluation tool (Hijmans *et al*. 2012). This analysis allows to evaluate how well model predictions discriminate between locations where observations are present or absent, and is one of the most widely used threshold-independent evaluators of model discriminatory power (Fielding and Bell, 1997). The criteria suggested by Swets (1988, cf. also Araújo *et al.* 2005) where adopted to interpret AUC range values as follows: excellent

(AUC > 0.90); good (0.80 < AUC < 0.90); fair (0.70 < AUC < 0.80); poor (0.60 < AUC < 0.70); fail (0.50 < AUC < 0.60).

2. Results

Two GIS-MPSA models and four MaxEnt models were implemented. The MaxEnt models implemented with 6 (Altitude, Aspect, River network, Riverbank borders, River erosion banks, MSAVI) or 7 (Slope, Aspect, River network, River erosion banks, MSAVI, NDVI, SAVI) of the environmental variables selected in the two ways, Pearson's coefficients ($M2_{200}$ model) and PCA ($M3_{200}$) respectively, resulted equivalent. However, the model ranking by means of the AICc and wAICc, (Table 1) indicates "some substantial support" ($\Delta AICc \leq 2$) (Burnham & Anderson 2002) for model in which the choice of the variable was guided by the Spatial PCA. That is, the competing $M3_{200}$ model has a higher support than the candidate best model ($\Delta AICc=0$) $M2_{200}$, whereas no support ($\Delta AICc>10$) resulted for the remaining $M1_{200}$ and $M0_{200}$ models.

Considering that for all models 66% of the presence data were used for the training and 33% for the test, the results of the ROC/AUC analysis clearly indicate the better performance of the "best MaxEnt model" ($M3_{200}$ AUC 0.75) in relation to the GIS-MSPA (AHP_3_{200} $T_{73}/G_{22}/VI_5$ AUC 0.51).

This indicates that the probability map corresponding to this model represents the probability of Neolithic sites' distribution in a more realistic way than its GIS-MPSA analogue (Fig. 2).

3. Discussion and Conclusions

This work demonstrates that in the case of the Tavoliere area, presence only SDMs models can be considered as more effective than GIS-MPSA ones for the modelling of archaeological site distribution. In addition, the best MaxEnt model resulted from the selection of variables performed by means of a spatial PCA. Therefore, this approach appears as an efficient and objective means to increase model parsimony, guiding the choice of the model with the most effective variable combination, while reducing the risk of overfitting.

This work shows that the application of high performance predictive methodologies is promising for the protection of buried cultural heritage and might enable an efficient management of economic and administrative aspects for territories characterised by a high archaeological risk. The work is however in progress, as we aware that a few issues (e.g. selection of the most effective map resolution, assessment of the relative importance of remote sensing data for the development of response variables) need to be explored with greater detail to allow for the transferability of the approach to other areas.

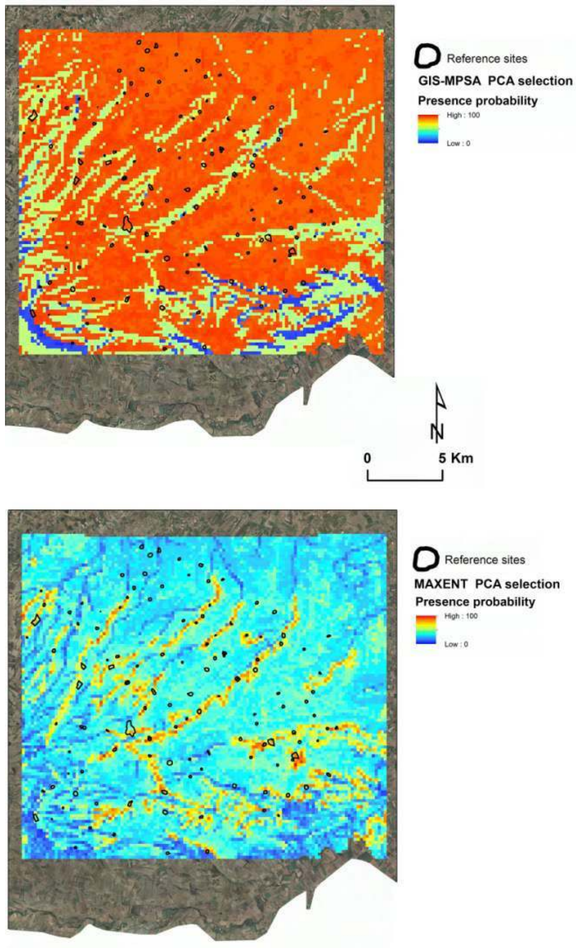

Figure 2 Probability maps (resolution 200 m x 200 m) corresponding to the best MaxEnt model (below) and to the analogue GIS-MPSA model (above).

Rank	Log Likelihood	Parameters	Sample Size	AIC score	AICc score	ΔAICc score	wAICc
$M2_{200}$	-1097.91	34	120	2264	2292	0.00	6.26E-01
$M3_{200}$	-1102.29	32	120	2269	2293	1.03	3.74E-01
$M1_{200}$	-1094.21	41	120	2270	2315	22.75	7.19E-06
$M0_{200}$	-1088.31	57	120	2291	2397	105.45	7.90E-24

Table 1 Results of AICc Analysis for the four competing MaxEnt models at 200 m scale.

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SATELLITE BASED INVESTIGATION FOR DETECTION OF ANCIENT TOMBS' LOOTING IN CYPRUS

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Περίληψη/Abstract

Η παρούσα εργασία πραγματεύεται την ανάλυση πολυφασματικών δορυφορικών εικόνων και αεροφωτογραφιών υψηλής χωρικής ανάλυσης (WorldView-2) και RGB εικόνων από το Google Earth©, με σκοπό τη χαρτογράφηση και διαχρονική παρακολούθηση περιοχών, οι οποίες υπόκεινται σε συστηματική σύληση από τυμβωρύχους. Η έρευνα επικεντρώνεται στην ευρύτερη περιοχή της αρχαιολογικής θέσης «Άγιος Μνάσωνας» στο χωριό Πολιτικό της επαρχίας Λευκωσίας, όπου έχουν εντοπιστεί πέραν των δέκα συλημένων αρχαίων τάφων. Οι παράνομες αρχαιοκαπηλικές δραστηριότητες στην περιοχή πραγματοποιήθηκαν σε διαφορετικές χρονικές περιόδους με τις εισόδους των τάφων να εντοπίζονται σε βάθος περίπου τριών μέτρων από την επιφάνεια του εδάφους. Οι αναλύσεις των δορυφορικών εικόνων σε συνδυασμό με επιτόπια έρευνα έχουν δείξει ότι το φαινόμενο αυτό δεν είναι μεμονωμένο περιστατικό, αφού και άλλες περιοχές δυτικότερα της θέσης που εξετάζεται στην παρούσα εργασία, παρουσιάζουν ίχνη διατάραξης. Η προτεινόμενη μεθοδολογική προσέγγιση αποδεικνύει ότι η ανάλυση εικόνων και η επεξεργασία πολυφασματικών δορυφορικών δεδομένων υψηλής χωρικής ανάλυσης, προσφέρει τη δυνατότητα συστηματικής παρακολούθησης περιοχών αρχαιολογικού ενδιαφέροντος, με σκοπό την προστασία και διαφύλαξη της πολιτιστικής κληρονομιάς από παράνομες δραστηριότητες.

This study aims to present the results from the analysis of high resolution multispectral satellite and aerial images (WorldView-2) and RGB images from Google Earth© engine in order to map and diachronically monitor sites of archaeological interest that are endangered from looting. The research concerns the archaeological landscape of *Ayios Mnason* in Politico village, located in Nicosia district, where more than ten looted tombs have been identified. Some of these tombs have been disturbed in the past, while others by more recent illegal activities, detected in depth of more than three meters below ground surface. Image processing and *in situ* investigations evidenced that this phenomenon is not isolated, since other areas in the western part of the case study under examination in this paper, have been also disturbed. Overall, it is evident that image analysis and processing of high resolution multispectral satellite datasets, can be used for systematic monitoring of areas with archaeological interest, in order to protect and safeguard cultural heritage against illegal archaeological activities.

Keywords: Archaeological Looting, Remote Sensing, Aerial Images, Satellite Images, Cyprus, WorldView-2, Google Earth©

Introduction

Illegal archaeological activity consists one of the major anthropogenic hazards of cultural heritage threatening several important archaeological sites of Cyprus. While illicit trafficking has been secured under various international treaties (e.g. The Hague Convention 1954, UNESCO general Conference 1964, European Convention 1969 etc.), the local law and its subsequent amendments, still the illicit archaeological excavation and particularly tomb looting, as far as Cyprus concerns, is even today a serious infestation threatening the history and archaeology of the island. It is therefore evident that a robust and systematic tool is needed in assisting legal and local authorities and stakeholders.

To this end remote sensing technologies, including space observation and ground non-contact techniques, can be of a great support for mapping and monitoring both the archaeological sites and the natural and anthropogenic hazards threatening them. Through remote sensing technologies current threats could be detected, mapped and thus observed and monitored, while in some cases prediction of threats could be achieved. The *a priori* consideration of potential threats of 'sensitive' archaeological areas could consist of a strategic tool towards their prevention.

Within the last years remote sensing has been systematically employed to support various aspects of archaeological research (Agapiou & Lysandrou

2015) and cultural heritage sector (Tapete *et al.* 2016). More recently, greater attention was given towards the exploitation of earth observation techniques concerning the destructions made in war conflicted areas, including amongst others, the documentation of looted sites (Tapete *et al.* 2016). The investigation and monitoring of illicit archeological activity from space has been also studied in vast areas of archaeological interest upon limited surveillance means (Lasaponara *et al.* 2012; Lasaponara *et al.* 2014).

Even though remote sensing cannot stop looters, it can positively impact to the distant monitoring of large scale sensitive areas, providing fruitful information to stakeholders in order to identify looting signs, as well as to distantly and efficiently record and monitor these sites, also preventing further destructions of this kind.

For the aims of this study, multi-temporal aerial images taken during 1993, 2008 and 2014, as well as a multispectral high resolution WorldView-2 image and RGB images from Google Earth© engine were used. The multi-temporal analysis of the various data-sources included the creation of pseudo colour composites, the use of vegetation indices and Principal Component Analysis. The preliminary results from the image analysis of the above datasets are hereunder presented.

1. Case study area and methodology

The area under investigation is located in the south western part of the modern village of Politico, in Nicosia District. In this area, looted tombs have been identified in the past as well as in more recent years. The tombs are hewn out of the natural bedrock. Undisturbed tombs are difficult to be detected by means of aerial and/or satellite techniques due the fact that they are underground, in an approximate depth of 3 meters below surface. In contrast, signs of looted tombs are more likely to be observed and recognised in that way (Fig. 1).

The wider area of the Politico village consists of an intense archaeological territory, very important for the history of Cyprus, linked to the ancient city-kingdom of Tamassos. While several archaeological excavations took place in the past or are still taking place in the area of Politico (Politiko-Kokkinorotsos 2007: La Trobe University, Melbourne under Dr. David Frankel and Dr. Jenny Webb, Politiko-Troullia 2016: University of West Carolina Charlotte, USA under Dr. Steven Falconer and Dr. Patricia Fall), the necropolis under investigation here has never been excavated or studied. Even though this area has been declared as an ancient monument (Scheduled B monument) and is protected by law, the looting not only has not ceased, but as will be shown hereunder, it has been augmented through the years.

Figure 1 Looted tomb. Looting has been achieved using mechanical equipment (depth more than three meters below ground surface).

The archaeological importance of the site is also documented in the first topographic map of Cyprus, drawn in the last quarter of the 19th century (Fig. 2).

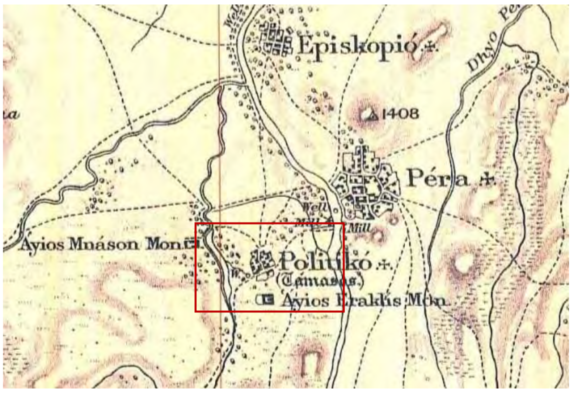

Figure 2 Case study area as indicated in the Kitchener's map, drawn in the last quarter of the 19th century.

For the specific case study, three high resolution aerial datasets have been exploited: (a) a grayscale orthophoto aerial image taken in 1993 with 0.50 m pixel resolution; (b) an RGB orthophoto aerial image taken in 2008 with similar pixel resolution and (c) an RGB orthophoto aerial image taken in 2014 with pixel resolution of 20 cm. Further enhancement of the results obtained by the analysis of the abovementioned aerial datasets, was given through processing a high resolution WorldView-2 satellite image taken at 11th of June 2009 and examining the historical record of the Google Earth© engine.

2. Results

Initially, a critical interpretation of the aerial images has been accomplished (Fig. 3a-c). Subsequently, the datasets were overlaid and several colour composites have been created (Fig. 3d-f). For instance, Figure 3d presents a pseudo colour composite before looting events have taken place and therefore no anomalies are detected contrary to the rest of the composites (Fig. 3e-3f).

In addition, Principal Components Analysis (PCA) was applied to the aerial datasets. Figures 3g -3h present the first two Principal Components (PCs) while Figure 3i presents a pseudo colour from the first three PCs. In the latter, the looted areas are easily recognised.

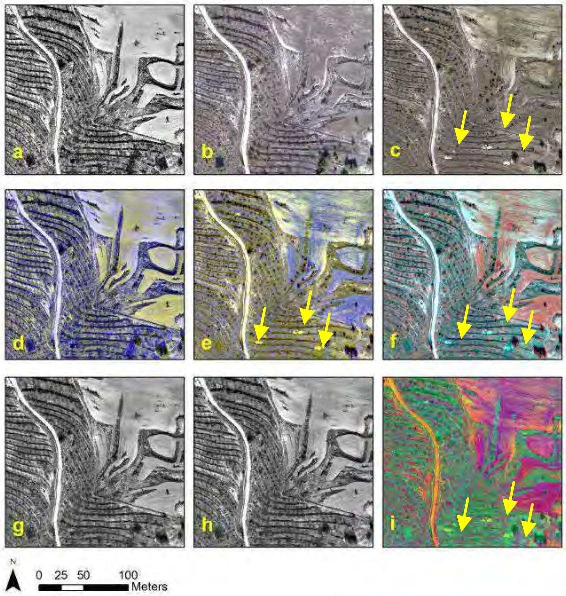

Figure 3 Grayscale orthophoto aerial image taken in 1993 with 0.50 m pixel resolution (a); RGB orthophoto aerial image taken in 2008 with similar pixel resolution (b); RGB orthophoto aerial image taken in 2014 with pixel resolution of 20 cm (c). Different colour composites have been created from these datasets (d-f), while (g-h) present the first two Principal Components (PCs) and (i) a pseudo colour from the first 3 PCs.

From the exploitation of the satellite datasets employed for this study, signs of looting have been identified in different periods covering a time span from 2008 until today (2016). Compared to the results of the aerial data, the satellite images have both identified even more looted tombs and provided information in relation to the looting period (Fig. 4).

Figure 4 shows the results from the image interpretation of WorldView-2 and Google Earth© images. Circles indicate areas looted at different times, demonstrating the expansion of looting from 2008 to 2016. Yellow circles are referring to the looted tombs that have also been identified in situ by the authors, while red circle defines a disturbed area detected only by satellite investigation.

Figure 4 Left: Worldview-2 pseudo colour composite of 2009 indicating one looted tomb in circle. Right: screenshots from Google Earth© engine indicating looted tombs of the same area between 2008 and 2016.

Moreover, other algorithms have been tested at the WordView-2 dataset (see Figure 5) including several vegetation indices (such as the Normalised Difference Vegetation Index – NDVI; Difference Vegetation Index – DVI; Atmospheric Resistance Vegetation Index – ARVI etc.) and other indices like the Sum Green Index and Build Up Index as well as the orthogonal linear equations (Agapiou 2017). The latest techniques allow to the enhancement of the satellite image by creating a new 3D spectral space, which is linearly correlated to the initial spectral bands of the sensors, namely soil, vegetation and crop marks.

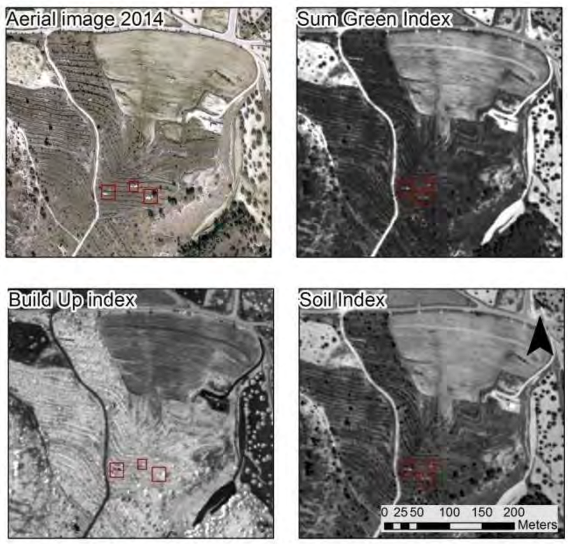

Figure 5 Aerial image indicating the looted areas in red squares (top left). The rest figures show the post-processing of the Worldview-2 image using different vegetation and other indices (such as Sum Green Index; Build Up Index) and linear orthogonal equations (soil component).

In addition, semi-automatic segmentation and classification techniques have been applied in both aerial and satellite data to evaluate their performance for the identification of looted areas. The semi-automatic segmentation was performed within the ENVI software using rule-based and object-oriented approach (Figures 6 and 7). Various parameters regarding the scale and the colour have been tested. Supervised and un-supervised classification of the image was also carried out within the same software. Un-supervised classification was performed using the ISODATA algorithm while supervised classifiers such as Mahalanobis distance and Support Vector Machine (SVM) have been applied. The classification was employed in order to examine whether the spectral properties of the looted areas could be detected from the multi-spectral sensor.

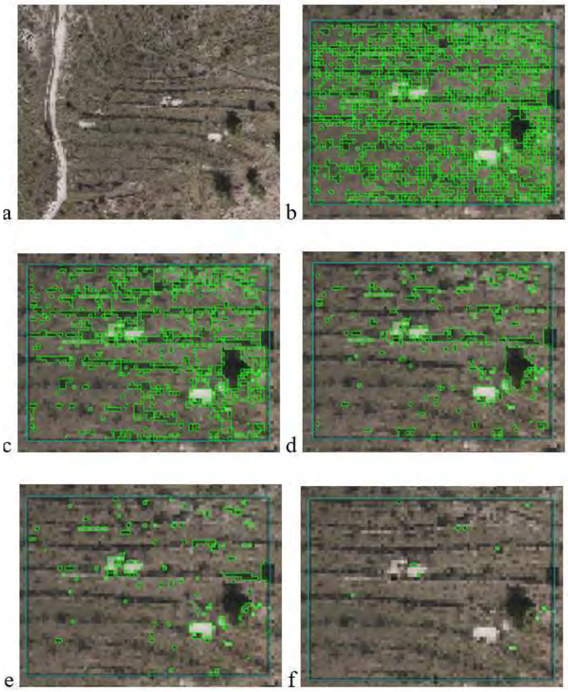

Figure 6 (a) Aerial image of 2014 (RGB) over the looted tombs; (b) Segmentation with 50 scale factor; (c) Segmentation with 60 scale factor; (d) Segmentation with 70 scale factor; (e) Segmentation with 75 scale factor and (f) Segmentation with 80 scale factor.

Figure 7 Simple rule base threshold values applied to the RGB bands of the orthophoto image acquired in 2014.

The overall results of the methodology for the specific case indicate that remote sensing techniques can be of great support to the authorities for monitoring tomb looting in vast archaeological landscapes, hard to be investigated systematically by other means.

Conclusions

The aim of the present paper was to evaluate the potential use of aerial and satellite datasets (object oriented classification compared to other classifiers, etc.) for monitoring tomb looting.

As demonstrated in this case study, protection and monitoring of sites and monuments (either known or still un-known) is feasible using remote sensing data and methodologies. While tomb looting identification was successfully achieved in the present research, this methodology could be useful (and further exploited) to identify other types of changes occurring in an archaeological landscape.

Remote sensing datasets can provide helpful information for stakeholders to monitor cultural heritage sites and landscapes. The piling of aerial and satellite data resulted in the identification of even more disturbed areas, upon different periods of time. The results clearly indicate that archaeological areas and landscapes can be monitored on a systematic basis to track and eventually prevent similar activities in the future, assisting local authorities to identify areas of high risk in relation to looting.

From an archaeological point of view, it is of great importance that this specific area, obviously a vast ancient cemetery laying to the west of Politico village has never been excavated and/or studied. The recurring loss of archaeological information and material from looting provokes an irreversible destruction to the archaeological layers and should be considered catastrophic for Cypriot archaeology.

It is important to highlight that the authors have accomplished in situ investigation prior and after image analysis, providing ground truth validation of the remote sensing results, thus permitting the evaluation of the techniques employed.

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3D MODELLING, VIRTUAL REALITY AND SIMULATIONS

THE DIGITAL HELIKE PROJECT: FURTHER INSIGHTS FROM ARCHAEOLOGICAL AND GEOLOGICAL DATA IN THE EARLY HELLADIC PERIOD THROUGH COMBINED MODELLING, 3D RECONSTRUCTION AND SIMULATION

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Περίληψη/Abstract

Το Ψηφιακό Πρόγραμμα Ελίκης εστίασε την πρώτη φάση της έρευνάς του στο Κτήριο με Διαδρόμους (ΚμΔ), που αποτελεί κεντρικό κτίσμα του Πρωτοελλαδικού (ΠΕ) οικισμού της Ελίκης στη βόρεια Πελοπόννησο. Η ίδια έρευνα παρείχε επιπλέον πληροφόρηση στην επίδραση της δυναμικής του τοπίου μέσω της προσομοίωσης γεωλογικών γεγονότων καθώς και στην κατανόηση του γενικότερου αρχιτεκτονικού σχεδίου του κτηρίου και των υλικών δομής του. Μία εφαρμογή Γεωγραφικών Συστημάτων Πληροφόρησης με βάση τη δυναμική μοντελοποίηση που βασίστηκε σε πέντε μεταβλητές τοπίου (άνοδο της στάθμης της θάλασσας, προσχώσεις, καθίζηση, τεκτονική ανύψωση) είχε ως αποτέλεσμα τη μοντελοποίηση της σχέσης μεταξύ της ΠΕ πόλης και της θάλασσας. Η θέση του οικισμού και η γειτνίαση με την ακτογραμμή είναι συνεπείς με τα αρχαιολογικά στοιχεία και τα δεδομένα των γεωτρήσεων του Ερευνητικού Προγράμματος Αρχαίας Ελίκης. Πραγματοποιήθηκε τρισδιάστατη αναπαράσταση του ΚμΔ που συνοδεύτηκε από ανάλυση της δομικής ακεραιότητας, μια πρωτοποριακή τεχνική εφαρμογής στην αρχαιολογία βασισμένη στην Ανάλυση Πεπερασμένων Στοιχείων. Η εφαρμογή της μεθόδου κατέδειξε ότι οι στενόμακροι διάδρομοι προστέθηκαν για να εξυπηρετήσουν βασική δομική ανάγκη που αφορά στην ενίσχυση των πλευρικών τοίχων του προκειμένου να αντέξουν το βάρος δεύτερου ορόφου και στέγης με κεραμίδες. Επίσης μακρόχρονες εικασίες σχετικά με την αρχιτεκτονική των ΚμΔ στην ΠΕ ηπειρωτική Ελλάδα αποσαφηνίστηκαν, ενισχύοντας περαιτέρω ερμηνευτικές προσεγγίσεις σχετικά με τον διοικητικό τους ρόλο.

The first phase of the Digital Helike Project has focused on the Helike Corridor House (HCH), the central building of the Early Helladic (EH) settlement in the northern Peloponnese. The research provides insights on the impact of landscape dynamics through simulation of geological events and on the overall HCH architectural design and construction materials through structural integrity studies. GIS-based dynamic modelling based on five landscape variables (sea level rise, deposition, subsidence, tectonic uplift, and pulse tectonic uplift) modelled the relationship between the EH town and the sea. The location and proximity to the shore are consistent with archaeological and borehole data from the Helike Project. 3D reconstruction of the HCH was performed followed by structural integrity analysis, a pioneering technique within archaeology based on Finite Element Analysis. The method has shown that the long narrow corridors had a structural function intending to improve side walls strength for supporting a second floor with a tiled roof. Long-standing conjectures have been refined regarding the architecture of corridor houses in the EH southern mainland, and has supported approaches to their administrative role.

Keywords: Helike Corridor House, Finite Element Analysis, GIS-modelling, Structural Integrity

Introduction

The Helike Project (Katsonopoulou 2011) has located an Early Helladic (EH) II-III settlement buried 3-5 m under the coastal plain of Aigialeia, in northern Achaea, on the southwestern shore of the Corinthian Gulf (Fig. 1). Evidence for elaborate town planning consists of buildings arranged across cobbled streets including one of the Corridor House type. Large amounts of stored domestic accessories and exotic wealth imply that the town had key access to the network of overseas trade during the middle and early second half of the 3rd millennium BC (Katsarou-Tzeveleki 2011).

The Digital Helike Project (DHP), under the umbrella of the Helike Project, is a multidisciplinary research effort aiming at understanding the EH Period through modelling and simulation. It integrates a range of data generated from borehole samples, archaeological excavation and stratigraphy, geophysical prospection, geological information, seismological evidence, environmental analysis, GIS, 3D reconstruction, structural integrity studies and cultural identification. Within this wider research framework, the first phase of the DHP focuses on the Helike Corridor House (HCH) within its landscape.

Figure 1 Map of the Peloponnese showing the location of the EH Helike.

The starting point of the research was to perform GIS-based predictive modelling to place the HCH in the context of the Helike Plain and ancient shoreline by simulating changes in the landscape over the past 4300 years (Kormann 2008). The main purpose of this study being to reconstruct the relationship of the EH town with the sea, given that the affluence of imported items from long-distance sea trade shapes the social character of the town. The EH site, including the HCH, is at present in the alluvial plain of Aigialeia and more particularly at the Helike Delta plain between the two rivers Selinous and Kerynites at about 1100 m from the present shoreline. It is buried at 3-5 m depth under the coastal plain pointing to the extent of dynamic changes of the landscape since the EH period (Soter & Katsonopoulou 2011, Engel *et al*. 2016). According to geoarchaeological and archaeological data yielded from research carried out by the Helike Project in the area during the past 25 years, the EH site of Helike was built on a low rise in the plain at about 200m distance from the coastline (Soter & Katsonopoulou 2011).

Following landscape modelling, structural integrity studies of the HCH have been performed through 3D reconstruction, modelling and simulation. While computer models have been used in cultural heritage before (Hejazi & Saradj 2014), the novelty of our approach lies in using structural integrity analysis, an engineering technique based on Finite Element Analysis (FEA), for the study of archaeological structures. The models are used as means of testing mechanical properties of building structures, which depend on construction techniques and materials used and are based on CAD models' geometry. In the case of the HCH the geometry was derived from the layout of the foundation walls. The method thus, is based on precise physical models requiring the specification of materials and their geometries, and simulates a structure's ability to withstand a large variety of loads.

The excavated walls of the HCH pose several questions which may be answered by structural integrity simulation such as:

- What is the structural value of the added corridors in terms of load bearing; can a clear indication be provided of whether a second floor might have existed?
- What were the structural properties of construction materials based on?
- Why and how was the plan of an earlier house modified resulting in long narrow corridors and what is their relationships to facilities on the ground and upper floors?
- How does the HCH compare with its contemporaries, the 'House of the Tiles' at Lerna and the 'Weisses Haus' at Kolonna, Aegina, in terms of design and building materials?

Section 1 describes the methodology for simulation of dynamic environments based on Digital Elevation Model (DEM) and structural integrity. Section 2 presents the results and a discussion with conclusions is provided in Section 3.

1. Methodology

1.a Dynamic Landscape Modelling

Previous research (Soter & Katsonopoulou 2005 & 2011, Alvarez-Zarikian *et al*. 2005 & 2008, Koutsios 2009) has addressed the geomorphology of the Helike Delta from the Early Helladic to the Late Roman periods and how geological events influenced the continuity and discontinuity of landscape occupation. Kormann (2008) has developed dynamic models applied to a DEM of the Helike plain which has been validated by extensive borehole, environmental and excavation data, and cross-validated against geological, archaeological and literary sources.

The models describe and simulate the relationship between sea and land from the present day to the EH period. The general equation to calculate the height of a point at any past time using its current DEM height is given by Kormann (2008):

$$H_{t1} = H_{t0} + (S_{t1} - U_{t1}) - R_U t - R_D t + R_S t \quad (1)$$

Where $t = (t_1 - t_0)$ is the time span with t_1 as the time at the end of simulation and t_0 is the present time. This assumes that time is expressed in BP (Before Present) and normally $(t1 - t0) > 0$, that is, the simulation is run back in time. The method is based on updating a digital elevation map through Equation (1), where the height of each point in the DEM is re-evaluated for a given time in the past. H is thus, the DEM height where H_{t1} is the height to be calculated and H_{t0} is the current height of a point on the map. S is subsidence event, U is the pulse tectonic uplift event, and the rates R_U, R_D and R_S are constant rates for tectonic uplift, deposition, and sea level rise assumed over the period considered. The quantification of such variables for the Early Helladic was mainly taken from Soter (1998).

The effects of these five variables (sea level rise, sediment deposition, subsidence, tectonic uplift and pulse tectonic uplift) on the DEM are depicted in Figure 2. Starting at "Present sea level" on the right of the picture, the models evaluate how each elevation has changed from the present to the Early Helladic period and earlier. Tectonic uplift raises the tectonic plate and in the past any point in the Delta was lower than it is today, so the *rate of vertical tectonic uplift* (R_U) has a minus effect (i.e. it is subtracted) from all current DEM heights. Since sediment deposition is always adding layers of soil over time and any point was lower in the past than it is today, the *rate of sediment deposition* (R_D) also has a minus effect and needs to be subtracted from all current DEM heights as we travel back in time.

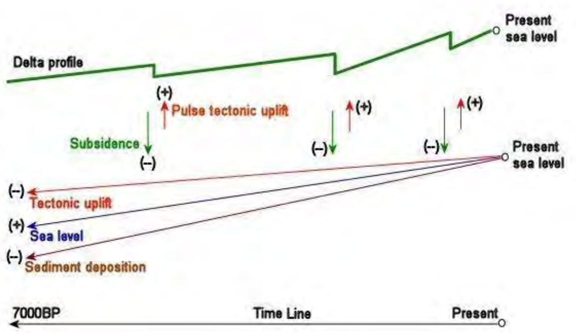

Figure 2 The behaviour of the five environmental variables over the past 7000 years with the effects plus (+) or minus (-) relative to current DEM elevations.

Since sea levels in the past were lower than the present day (Soter 1998), any point in today's DEM is higher in relation to the past sea level, so the *rate of sea level rise* (R_S) is added to DEM heights to represent this relative rise. Pulse tectonic uplift and subsidence only happen during the event of major earthquakes and thus, *pulse tectonic uplift* (U) raises the plate and must be added while *subsidence* (S) lowers the plate and must be subtracted. The quantification of the variables follows mostly from Soter (1998) and results described in Section 2.a are consistent with the archaeological records of the Helike Project and literary sources (Kormann 2008).

The dynamic landscape modelling discussed here is validated by archaeological records suggesting that the Early Helladic site was at sea side cf. Figure 4, trenches H21, H22 and bore hole B75 also cross-referenced by literary sources (Kormann 2008). Recent research has focused efforts on modelling the Early Helladic Helike Corridor House, a monumental building within the settlement through structural integrity analysis. The method is described in the next section and modelling results in Section 2.b.

1.b 3D Modelling and Structural Analysis

Finite Element Analysis (FEA) is a simulation and analysis method to study the behaviour of engineering structures under a variety of loads. By defining the geometry of the structure, materials, and the mechanical properties of such materials it is possible for instance, to simulate its dynamic behaviour, detect weaker points and improve the design. In archaeology, it is proposed to test whether structures such as buildings for which only scant evidence are available (e.g. where only foundation walls survive) would withstand the forces and displacements if they were built as suggested by the archaeological record (Kormann *et al.* 2015, Kormann *et al.* 2016).

Structural integrity studies using FEA require the specification of the geometry through a 3D model of the structure to be simulated. Several CAD packages can be used to create a 3D model; we have chosen SketchUp for its ease of use, being freely available, and its ability to export 3D file formats that are compatible with ANSYS, an engineering software package designed to simulate interactions of all disciplines of physics such as vibration and structural.

In the case of the HCH, ANSYS is used to test the integrity of the structure concerning materials, geometry and its ability to withstand loads. We have performed linear buckling analysis to determine at which level the load from the weight of a possible second floor and the roof might render the structure unstable. Developing such simulation analysis in ANSYS requires the following workflow:

- Define the analysis to perform (e.g. linear buckling),
- Specify materials engineering data, i.e. their mechanical properties which include the material's density, compressive and tensile yield strengths, Young's modulus of elasticity and Poisson ratio,
- Define the geometry of the structure as a solid 3D model,
- Specify the physical model and assign materials to various parts of the structure,

- Set up the initial forces and loads acting on the structure,
- Define a solution to perform (e.g. stress). The APDL (ANSYS Parametric Design Language) is used to solve the physical model and perform the simulations.

The results of the simulation can be viewed and analysed in various ways, and it can show clearly whether the structure would stand the applied loads (e.g. withstand the weight of a second floor and roof).

2. Results

2.a Dynamic Landscape Modelling

GIS-based predictive modelling simulating changes in the landscape over the past 4300 years (Kormann 2008) revealed the close relationship of the EH town with the sea. The model has shown that the HCH was located at 170 m from the ancient shoreline. The model has been validated by archaeological and environmental data. Our methodology uses present-day DEM SRTM90 (Shuttle Radar Topographic Mission, 90 m horizontal resolution) data. Imagery from Google Earth of the Helike Delta and shoreline is overlaid on to DEM as depicted in Figure 3. From the present-day model, the variables defined in Equation (1) change each elevation value with the long-term trend back in time as described in the methodology depicted in Figure 2. For instance, any point on today's shoreline would be submerged in the EH period.

Subsequently, the model was calculated for the period of *c.* 2300 BC and simulation results are depicted in Figure 4. The trenches and boreholes showing evidence of EH occupation is overlaid on the DEM raster image. The resulting model depicted in Figure 4 is in good agreement with cultural and environmental features that have already been revealed by analytical research data, including:

- the extensive expanse of the EH settlement encompassing the HCH, as implied by excavation (indicatively marked here by trenches H7, H21, H22);
- the presence of a lagoon (encircled area) implied by evidence from geo-archaeological research of the Helike Project; and
- the close distance to the sea side, as revealed particularly by evidence from bore hole B58.

In borehole B58 ceramics dating to 2300 BC were recovered from sandy clay at a depth of 3.0 – 4.20 m, underlying a brackish sediment containing ostracods together with evidence of a tsunami (Alvarez-Zarikian *et al*. 2008). The evidence suggests that the EH settlement was situated close to the shore. It was destroyed by an earthquake followed by a tsunami, in around 2300/2200 BC, and was then subsided in a marine environment. EH sediments from the excavated trenches have provided evidence of long term submergence of the buildings in a mixed environment of marine, lagoonal and terrestrial type before they were completely covered by river-borne deposits.

Figure 3 The present Helike Delta shoreline.

Figure 4 Simulation of the EH Helike shoreline, for the approximate date of 2300 BC.

The GIS results, also visualised in Figure 5, show that the HCH and the EH settlement were located at 170 m south of the EH coastline, found currently at 1100 m from the shore. The location and proximity of the HCH to the shore are consistent with data acquired from other contemporaneous Corridor Houses across the Peloponnese.

2.b 3D Modelling and Structural Analysis

The geometry of the HCH structure was developed from the excavated foundation walls and full plan drawing, depicted in Figures 6 and 7. The model was constructed in SketchUp and exported to IGS, a 3D file format designed to exchange 3D data. The full 3D model of the HCH, shown in Figure 8, was then directly imported into ANSYS. To build a simulation model with ANSYS, the mechanical properties for each material are required.

Figure 5 The relationship between the HCH and shoreline within the EH settlement.

Figure 6 Excavated walls of the HCH.

These properties must include density, Young's modulus of elasticity, Poisson ratio, and the compressive and tensile strengths. The geometry of the house depicted in Figure 8 was separated into groups according to their structural materials: 1) Foundation, 2) Walls, 3) Floor, including wooden structure, reed structure, and mud layer, and 4) Staircase. These structures differ extensively in terms of their range of materials and consequently their physical properties, which implies a range of mechanical responses.

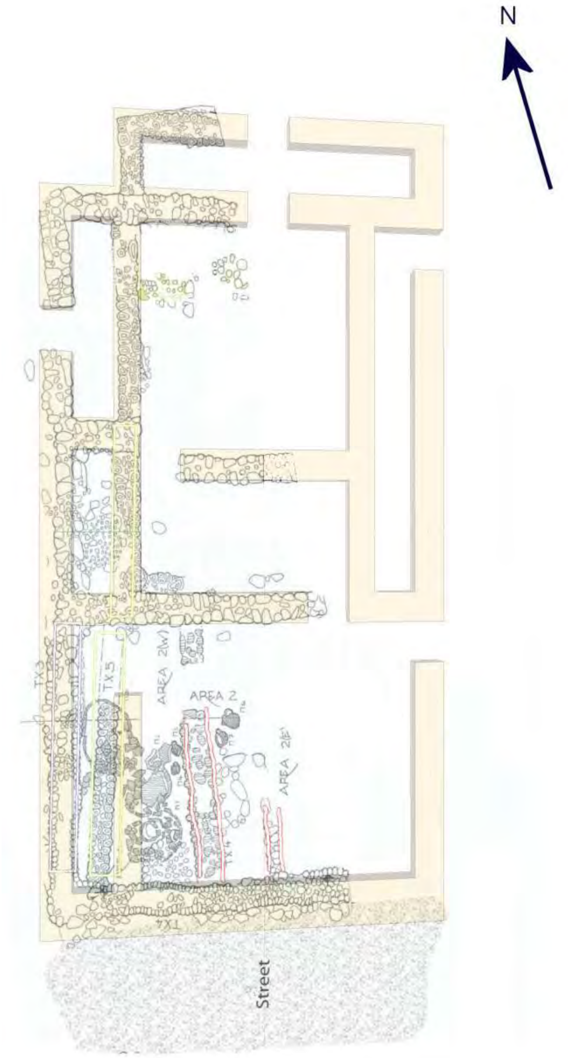

Figure 7 Plan of the HCH.

Figure 8 Full 3D reconstruction of the HCH.

A meshing operation subdivides the geometry into small components over which the method of FEA is applied determining the displacements for each applied load or force. The weight of the roof acting on the wall structure is defined by a single compression force. The roof was calculated as a total downward force of 262,244 N acting on the walls. The walls are fixed to the foundations and their motion is constrained in all directions. ANSYS then solves the analysis using the finite element method.

We placed our emphasis on performing buckling analysis which is used to determine the buckling loads, i.e., the loads in which the structure becomes unstable (Hibbeler 2013). The analysis is achieved by gradually increasing the load until it reaches the value specified by the roof load. The technique is widely used in engineering simulations to test slender structures such as walls and columns.

Results showing areas of the building that are more susceptible to buckling are depicted in Figure 9. The numeric results of buckling analysis are given by the load multiplier which can be used as a prediction of structural stability. Simulations were performed with several different scenarios and internal wall configurations and location for the staircase. The simulations show that the narrow corridors with stairs along the side walls have a structural function as they reduce the susceptibility to buckling. Equally, the plan of the internal cross walls increases the rigidity of the structure. Furthermore, the back wall which is considerably wider than the other walls has also the structural function of reducing susceptibility to buckling. Overall, the added corridors to the plan of the house were necessary features for supporting a second floor.

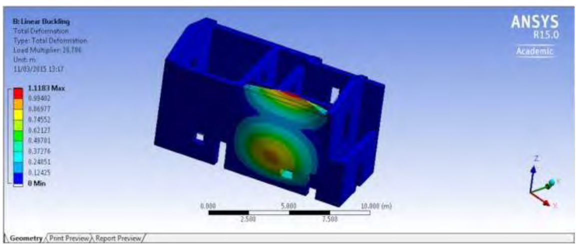

Figure 9 Linear buckling analysis. The areas shown in red are the most critical to buckling.

Discussion and Conclusions

This paper has described research carried out by the Digital Helike Project across a range of simulations spanning from dynamic landscape modelling and 3D reconstruction to structural integrity analysis using finite element methods. The focus has been on the EH town of Helike, on the southwest coast of the Gulf of Corinth, and the outstanding HCH, one of the best examples of a monumental corridor house type. Research aimed at expanding our insights into the cultural landscape of the site explored issues such as architectural plans and building materials through structural integrity analysis, and the extent in which building expertise was shared across the region in terms of architectural design in response to the emerging needs of a central administration and social status. The GIS dynamic model of the Helike landscape in the EH period has clearly demonstrated, in line with borehole and archaeological data yielded from the Helike Project research in the area, that the location of the site was close to the shoreline. This explains the large input from overseas trade providing evidence that the EH town of Helike had easy accessible trade routes through the Gulf of Corinth.

3D reconstruction of the HCH followed by structural integrity analysis using FEA, an engineering methodology applied to archaeology by this research has demonstrated the functional purpose of the corridors in EH architecture and have clarified a long-standing debate on the issue. Results from the HCH analysis have highlighted the required craftsmanship from the builders and problem-solving techniques by constructing a two-storey house with additional structural features such as the doubling of the walls into 'corridors' on the long sides as a structural strengthening element. These and other features such as transversal walls and the addition of a staircase enabled the house to withstand the loads of an upper floor and tiled roof.

Results from this analysis have revealed the specialisation of EH Helike builders on creating architecture upon a consistent and purposeful plan. Furthermore, results have provided valuable insights into the social purpose of building innovations occurring in the EH, to serve centralised administration, accumulated wealth and social status exemplified by corridor houses (Maran & Kostoula 2014, Shaw 2007, Wiersma 2013). Similarities in terms of overall plan design between the HCH and the Weisses Haus at Aegina, as well as with the House of the Tiles at Lerna may also account for a scenario where the plan and building techniques of the corridor houses have acquired a standardised form, which was optimised, copied and reproduced by expert architects and builders across the region, as part of a regime aiming at constructing social landmarks inside the EH town centres.

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LIVING IN THE GLOOM

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Περίληψη/Abstract

Στο παρόν άρθρο εξετάζεται η δυνατότητα εκτέλεσης οικιακών δραστηριοτήτων στην αρχαιότητα κατά τη διάρκεια της νύκτας με χρήση λύχνου, ως προς την αντίληψη των χρωμάτων και τη δυσκολία διάκρισής τους. Στο Εργαστήριο Φωτοτεχνίας του Ε.Μ.Π. πραγματοποιήθηκε σειρά τρισδιάστατων προσομοιώσεων με χρήση παλέτας (ομάδες χρωματιστών τετραγώνων), η οποία προσομοιώνει για τις ανάγκες των αναλύσεων τις οικιακές εργασίες. Με τον τρόπο αυτό υπολογίσθηκαν οι τιμές λαμπρότητας και οι ανάλογες παράμετροι για τη διάκριση των χρωμάτων. Σύμφωνα με τα αποτελέσματα, υπό τις προκύπτουσες συνθήκες φωτισμού, ομάδες χρωμάτων φαίνεται ότι αποδίδουν τις ίδιες τιμές, όπως το χρυσό, το γαλάζιο και το μωβ ή το μπλε με το μαύρο. Προκύπτει ότι η επιτυχής εκτέλεση δραστηριοτήτων που απαιτούν διάκριση χρωμάτων, όπως η υφαντική, δεν μπορεί να βασιστεί στην όραση κατά τη διάρκεια της νύκτας και υπό το φως που παράγεται από ένα λυχνάρι, αλλά απαιτεί εκ των προτέρων γνώση της θέσης της κάθε κλωστής.

This paper aims to investigate the feasibility of indoor nocturnal activities in houses of antiquity in terms of colour perception under the lighting conditions resulting from the use of lamps and the ability or discomfort for users when discriminating colours. A set of 3D simulations were performed in the Lighting Laboratory of the National Technical University of Athens using different colour pallets (sets of lines and squares) in order to simulate domestic tasks. The luminance values extracted from the surface of the pallet and the corresponding parameters for colour discrimination were calculated. According to the results among some sets of colours, for example gold, light blue and purple or blue and black, the measured difference is almost negligible. Consequently weaving, which requires colour discrimination, cannot be successfully performed during night-time under the resulting lighting conditions based on human vision alone, since it requires previous knowledge of the series of the threads.

Keywords: 3D simulation; Ancient Lighting, Colour Recognition, Low Lighting Levels, Photometric Calculations

Introduction

In recent years, there has been an increasing interest in the investigation of the performance of ancient lighting devices and the lighting conditions they bring about (For example Devlin & Chalmers 2001, Roussos 2003, Dawson *et al.* 2007, Happa *et al.* 2009, Papadopoulos & Earl 2009, Moullou & Topalis 2011, Moullou *et al.* 2012a & 2012b, Moullou *et al.* 2015, Moullou & Topalis in press). Among them experiments on copies of ancient lighting devices, measurements and photometric calculations that have been conducted at the Lighting Laboratory of the National Technical University of Athens have shown that in most cases the ancient lighting devices created very low lighting conditions (Moullou *et al.* 2012b, Moullou *et al.* 2015). In fact, the resulting values fall in the range of mesopic vision (the intermediate level of human vision where there is not adequate visual acuity and accurate colour recognition) and sometimes under scotopic (achromatic) vision.

The corresponding lighting simulations of rooms of ancient houses modeled according to the archaeological data (Moullou *et al.* 2012a & 2012b, Moullou *et al.* 2015), have shown that people in antiquity could operate with relative ease at night and could perform most of their nocturnal activities, with the use of one lamp provided that the lamp was placed appropriately inside the room.

Activities that involve colour recognition, such as weaving are, however, still under investigation mainly because there is doubt concerning their feasibility under the resulting lighting conditions.

The experiments of Pokorny *et al.* 2006, established a minimum illuminance threshold for colour recognition at 0.316 lux. This amount of light intensity is achieved with the use of one lamp. However, Pokorny *et al.* used samples of greater size (5-cm-square) than the thin threads used for weaving the elaborate cloths of ancient Greece. Therefore, the threshold of 0.316 lux cannot be convincingly applied to this activity.

While all lighting levels for indoor activities are given in illuminance values lx (BSI, 2011) the light that the human eye perceives corresponds more accurately to luminance values (cd/m^2). Thus, luminance can be considered as the main factor for colour distinction. Whereas illuminance is a measure of how much light is landing on a surface, luminance is a measure of how much light the eye is receiving from that surface.

This paper attempts to further investigate this issue by exploring the properties of colour during weaving at night under the low lighting conditions resulting from the use of a lamp.

1. Human Vision.

Before we proceed to the calculations it is important to introduce the reader to the basics of human vision and most importantly how the human eye sees. The human eye perceives the visible spectrum in order to interpret the surrounding environment. Photons of light are detected by the photoreceptive cells of the retina. There are two types of photoreceptive cells: cones and rods. Cones are responsible for colour perception and there are three different types with one for each basic colour: red, green and blue. Rods are responsible for the achromatic perception of objects in low light. When low light levels occur (< 3 lx.) the human eye can't perceive colours and so uses scotopic vision via the rods. Above 10 lx. the human eye uses photopic vision because of the activation of the cones resulting in the discrimination of colours. In the in-between lighting levels there is an intermediate vision called mesopic when rods and cones detect light photons (DiLaura 2011).

2. Methodology

In order to evaluate the perception of colours and the ability of people in antiquity to discriminate them under corresponding lighting levels, a methodology using lightness was performed. Lightness is a relative term that means brightness of an area judged relative to the brightness of a similarly illuminated area that appears to be white or highly transmitting.

$$L^*=116(L/Ln)^{1/3}-16 \quad \text{(eq. 1)}$$

Where: L*: is lightness of a colour patch, L: luminance deriving from the colour patch (cd/m^2) and Ln: luminance deriving from a white point as a reference (cd/m^2) (CIE Lab colour model). Furthermore, the lightness was introduced to the colour model of CIE 1976 (Fig.1) for estimating the colour difference.

Using two colours (L^*_1, a^*_1, b^*_1) and (L^*_2, a^*_2, b^*_2) the colour difference is defined by equation 2.

$$\Delta E^*_{ab} = \sqrt{(L^*_2 - L^*_1)^2 + (a^*_2 - a^*_1)^2 + (b^*_2 - b^*_1)^2} \quad \text{(eq.2)}$$

Where: L*: is lightness and a,b* the colour coordinates (Figure 1).

Figure 1 CIE 1976 colour coordinates.

Using scotopic vision (no colour discrimination) the equation 2 transforms to:

$$\Delta E = \Delta L \quad \text{(eq. 3)}$$

This means that the colour difference is equal to lightness difference between two sample patches in scotopic vision. A barely noticeable difference occurs when $\Delta E=\Delta L>3$.

In order to evaluate lightness, a set of 3D simulations were performed to evaluate luminance values of colour patches and luminance deriving from a white point as a reference (Jain 1989, Fairchild 2005).

3. Simulations

Simulations of the impact of ancient lighting devices on colours is a complex procedure because many parameters and measurements are needed including the elements of the lamps, the physical properties of the rooms, the type of activity under investigation and the elements and colours of the examined materials.

Lighting simulation allows the researcher to analyse the lighting conditions inside a room and the 3D distribution of lighting intensity as well as to calculate any photometric quantities such as illumination and luminance inside a predefined area.

In this research, the simulations were performed using a predefined colour pallet of typical colours that is used in contemporary lighting analysis, where the colour samples represent basic colour categories. The colour pallet was placed on a hypothetical loom. The hypothetical loom was placed in virtual rooms, modelled after the rooms of houses in the ancient city of Olynthus, in which both looms (or indications of their presence) and lamps were found (Moullou 2013, 25). Taking into account the reflectivity of the surfaces two rooms were selected; Room a of House A v 2; a room with plain mud brick walls (low reflectance) and Room a/b of the House of Many Colours; a room with white plastered walls (high reflectance).

Luminance values extracted from the surface of the pallet and the corresponding parameters such as L* lightness (equation 1) for colour discrimination ΔE (equation 3) were calculated. The resulting luminance calculations allowed us to derive conclusions regarding the recognition of colour.

3.a Input data

The lighting data used for the simulations was derived from photometric data and calculations conducted in the Lighting Laboratory of the National Technical University of Athens (NTUA) (Moullou & Topalis 2011, Moullou *et al.* 2015). The values and properties used were the ones for one lamp (lamp A), with olive oil as a fuel and a linen wick of 1 cm thick and 1 cm free length (the length of the wick outside of the nozzle which is available for burning) (Fig. 2). The selected colours of the predefined colour pallet are shown in Figure 3. The reflectance's properties of each tested colour are presented in Table 1.

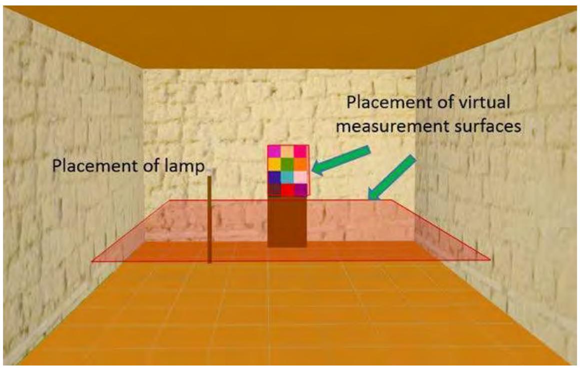

Figure 2 Placement of the predefined colour pallet of typical colours in the room with white plastered walls.

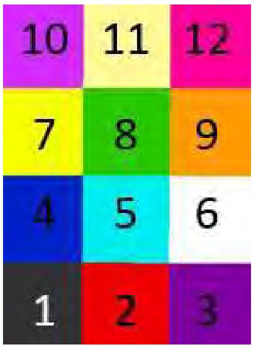

Figure 3 The selected colours of the predefined colour pallet.

Sample colour	Reflectance (%)			
	Total	Red	Green	Blue
1	2.9	2.9	2.9	2.9
2	22.5	84.8	0	0
3	8.0	21.6	0	34.8
4	4.4	0	1.1	57.1
5	62.3	0	84.8	84.8
6	100	100	100	100
7	91.4	92	100	91.4
8	38.7	1.6	57.1	0
9	48.6	100	32.9	0
10	25.5	67.1	2	98.7
11	91.6	100	94.2	30.8
12	28.6	100	0	32.5

Table 1 The reflectance's properties of each tested colour (Total reflectance and reflectance of each basic colour).

3.2 Calculations

Using lamp A, the total average illuminance of the tested rooms was below 1 lx (Figures 4 and 5). Meaning that depending on the individual person the human vision was either scotopic or mesopic.

Figure 4 Photometric results for illuminance values for room with plain mud brick walls.

Figure 5 Photometric results for illuminance values for room with white plastered walls.

Under these lighting conditions photometric results from a computer simulation tool are presented in a different way (Fig. 6) than scotopic vision (Fig. 7) and how an actual person could see (Fig. 8).

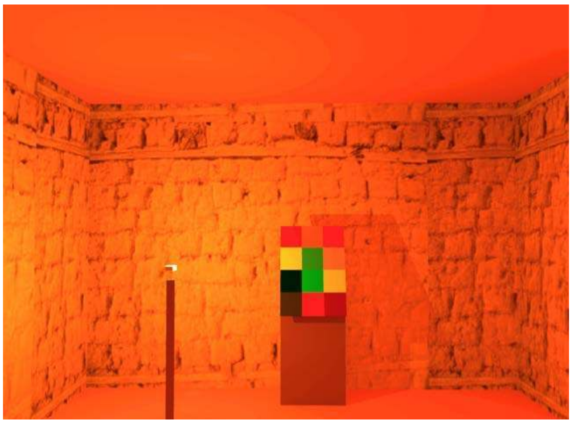

Figure 6 Presentation of photometric results from a computer simulation tool (Relux Desktop).

Figure 7 Presentation of photometric results from a computer simulation tool for scotopic vision (Relux Desktop).

Figure 8 Representation of how the human eye sees under the given circumstances (Relux Desktop).

5. Results

The calculated lightness values are shown in Figure 9.

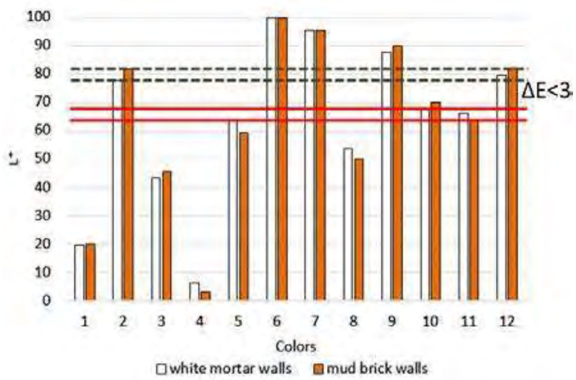

Figure 9 Calculated values of lightness for 12 colours and the two typical rooms and colour differences ΔE.

In the simulation of the room with plain walls the lightness values of purple (62) light blue (62) and gold (63) are very close. Also, blue and black have resulted in the same luminance values: 19 each. The aforementioned results mean that those sets of colours would appear the same. Furthermore, red (67) and pink (70) are also very close with a difference that might be barely noticed by the human eye.

The simulation of the room with white walls shows better results in terms of colour recognition and yet is no less surprising. In this case the sets of colours that present practically no difference for the human eye are purple (68) and gold (66), gold (66) and light blue (64) as well as red (77) and pink (80).

6. Conclusions

The experiments and simulation scenarios show that weaving as a nocturnal activity in antiquity was performed under low mesopic vision (less than 2 lx) for some persons, and very close to scotopic vision for many more. The discrepancy between scotopic and mesopic vision is subjective and depends on the physiology of each human subject.

It is evident that weavers in antiquity would have had inaccurate colour discrimination. The simulation results confirm the hypothesis that the discrimination of the colours of thin threads must have been very difficult and, in some cases, even impossible. The results strongly support the fact that the ancient weaver would not rely on his or her eyes. He or she would have had to develop excellent mnemonic skills since all of the calculations for the realisation of patterns would need to be mapped mentally prior to weaving.

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RECONSTRUCTING ANCIENT THEATRES ACCORDING TO VIRTUAL ACOUSTICS ANALYSIS

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Περίληψη/Abstract

Είναι συχνά περίπλοκο να κατανοηθεί και να ερμηνευτεί κάτι που ανήκει στο παρελθόν. Γίνεται ακόμα πιο δύσκολο όταν δεν υπάρχουν αρχαιολογικά ευρήματα ή αρκετά στοιχεία ώστε να περιγραφεί η δομή και η χρονική εξέλιξη ενός μνημείου ή αρχαιολογικού χώρου. Ευτυχώς, τα τελευταία χρόνια, η τεχνολογία ενισχύει την δυνατότητα να δημιουργηθούν πιστές ανακατασκευές του αρχαίου κόσμου. Αυτή η εργασία παρουσιάζει μια νέα μεθοδολογία που βοηθά στην παραγωγή αρχιτεκτονικών αναπαραστάσεων των μνημείων με μεγάλη ακρίβεια. Η εικονική ακουστική ανάλυση του Ρωμαϊκού θεάτρου της Γόρτυνας, στους Καζινέδες, αναδεικνύει ότι η δοκιμή της ποιότητας ακουστικής είναι απαραίτητη για την επικύρωση υποθετικών ανακατασκευών. Ως εκ τούτου, μπορεί να φανεί χρήσιμη στο να ερμηνεύσει σωστά την αρχιτεκτονική δομή των κτηρίων, όπου η ακουστική αποτελεί θεμελιώδη πτυχή.

The interpretation of the past is even more difficult when there are not archaeological remains or not enough evidence to describe the structure and the time evolution of a monument or an archaeological site. Luckily, in the last years, technology enhances our possibility to create more faithful reconstructions of the ancient world. This paper presents a new methodology that helps to produce more accurate architectural reconstructions of monuments. The virtual acoustics analysis of the Roman theatre of Gortyna, at Kazinedes, highlighted that the test of the acoustics' quality is essential to validate hypothetical reconstructions. Therefore, it can be helpful to correctly interpret the architectural structure of buildings where acoustics is a fundamental aspect.

Keywords: Roman Theatres, Gortyna, Virtual Acoustics Analysis, 3D models

Introduction

Greek and Roman theatres are well-known for their exceptional acoustics, which intrigues many archaeologists but also specialists of acoustics since many years. In the 1st century BC, Vitruvius dedicated one section of his work to the acoustics of the ancient theatres. He distinguishes four kinds of room which influence the acoustics in different way: *desonantes*, where the first sound obstacles the following one; *circumsonantes*, which creates sounds of indistinctive meanings; *resonantes*, which produces echo; and *consonantes*, where the words are distinct and clear in tone (Morris 1914). This description demonstrates the wide knowledge the Romans had about acoustics and we can assume theatres were built aiming to obtain a consonant space, the best one according to Vitruvius.

The first scientific detailed research about the study of the acoustics of ancient theatres is dated to 1967 (Canac 1967). François Canac carried out real acoustics measurements in some of the best preserved theatres (such as Aspendos, Orange, Arles, Ostia, etc.) and together with some laboratory analysis, he tried to discover the acoustics' role of some architectural parts of some theatres of the ancient world. From his studies, he concluded that:

- the retaining walls (*analemmata*) of the cavea protect from the wind and external noises;
- the wall of the scene building and the floor of the orchestra are reflective surfaces;
- reliefs, statues and niches have the function to diffuse late reflections;
- often, the roof creates late reflections, which have a negative impact on the acoustics;
- *parodoi* absorb the sound on the sides to avoid the echo.

In the following years, only single and short in-depth studies about the acoustics of the most famous theatres (Epidaurus, Pompeii, Ostia, etc.) appeared. In 2003-2006, the ERATO project (Identification, Evaluation and Revival of the Acoustical Heritage of Ancient Theatres and Odea) has stimulated a concrete interest in this topic.

Above all, the acoustics of several theatres (Aspendos, Aphrodisa, Jerash, Syracuse, etc.) have been virtually analysed through the creation of 3D models and the software Odeon Room Acoustics, produced by the Danish company Odeon A/S (Rindel

& Lisa 2006). One of the studies within this project was about changes in the acoustic characteristics in relation to architectural modifications. The analysis was carried out virtually with regard to the theatre of Aspendos and to the odeon of Aphrodisia (both in Turkey), with the additional aim to review Canac's theories (Lisa *et al.* 2006). Furthermore, the project has demonstrated the utility of virtual acoustics analysis of ancient theatres in order to plan a reutilisation of those spaces (Vallet *et al.* 2006). More recently, the Odeon of Pompeii has been virtually reconstructed and its acoustics have been analysed. It has been demonstrated that there is a lot of information to be obtained through this methodology about the quality of the sound in this space (Berardi *et al.* 2016).

This paper aims to show how virtual acoustics analysis of ancient theatres not well preserved can help validate the interpretation of their remains, and to improve the reliability of their 3D architectural reconstructions.

1. Theoretical aspects and case study

The software Odeon Room Acoustics, allows to virtually analyse the acoustic characteristics, and therefore the acoustics' quality of a reconstructed room in a 3D environment (Christensen & Koutsouris 2013). The sound is characterised by three components: direct sound (it is the one that travels on a straight line from the speaker to the listener), early reflections (reflections that arrive within 30 millisecond after the direct sound, they improve the quality of the sound) and late reflections (they arrive after 30 milliseconds from the direct sound, they can have a negative impact on the acoustics).

Odeon Room Acoustics measures the impulse response (which contains information about the sound received) for each receiver placed in the 3D space, in order to obtain the values of some parameters that give information about the acoustics. The evaluated parameters in this research are: reverberation time and early decay time that are connected to the reverberation of the sound, clarity and definition that are related to energetic criteria, and finally, speech transmission index that it is about the spoken intelligibility. The reverberation time is the time a sound takes to decrease by 60 dB after it stops (T60); for speech performances, the ideal value is around 1 second. The first 10 dB of decay (early decay time, EDT) are also important to consider because they represent the subjective perception of the reverberation, which is related to the feeling of how much these reflections annoy the listener. Furthermore, EDT indicates the diffusion of the sound: in an ideal environment, it should be the same as T60, but it is usually little lower and the disparity between them is a signal of good or bad diffusion of the sound. Previous researches about well-known and well preserved theatres (Aspendos, Epidaurus, Jerash) demonstrated that usually, in open-air theatres, the difference between T60 and EDT is between 0.2 and 0.4 seconds (Gade & Angelakis 2006).

Clarity (C80) represents the comprehension of single sounds within a complex signal. It consists of the ratio between the energy (of the sound) that arrives within 80 milliseconds (the direct energy plus the energy of early reflections) and the energy that arrives later. If the energy of the late reflections is higher than the energy of direct sound and early reflections, clarity, which means comprehension, is not good. We have an appropriate clarity for speech when its value is equal or greater than 3dB. Definition (D50) indicates the level of clarity of the speech, the ease for the listener to understand the message of the speaker. The index of D50 is the ratio between the energy that arrives within the first 50 milliseconds (direct sound plus early reflections) and the remaining energy of the signal. Also in this case, the first energy has to be superior to the late energy in order to have an acceptable quality of the acoustics for the speech. The value of D50 has to be higher than 0.50 (by definition it is included within 0 and 1).

Figure 1 Ortho photo of the area of the theatre at Kazinedes, Gortyna (Google Earth).

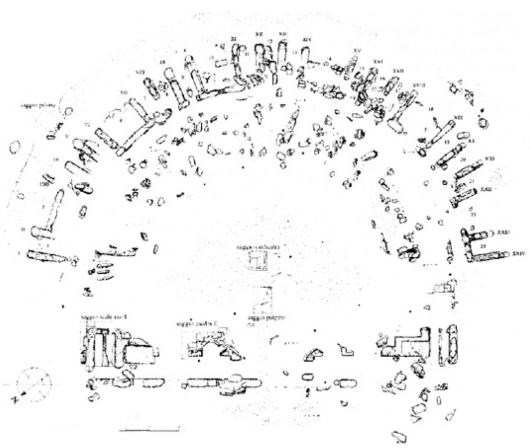

Figure 2 Survey of the remains of the theatre at Kazinedes by Montali (with permission from the author).

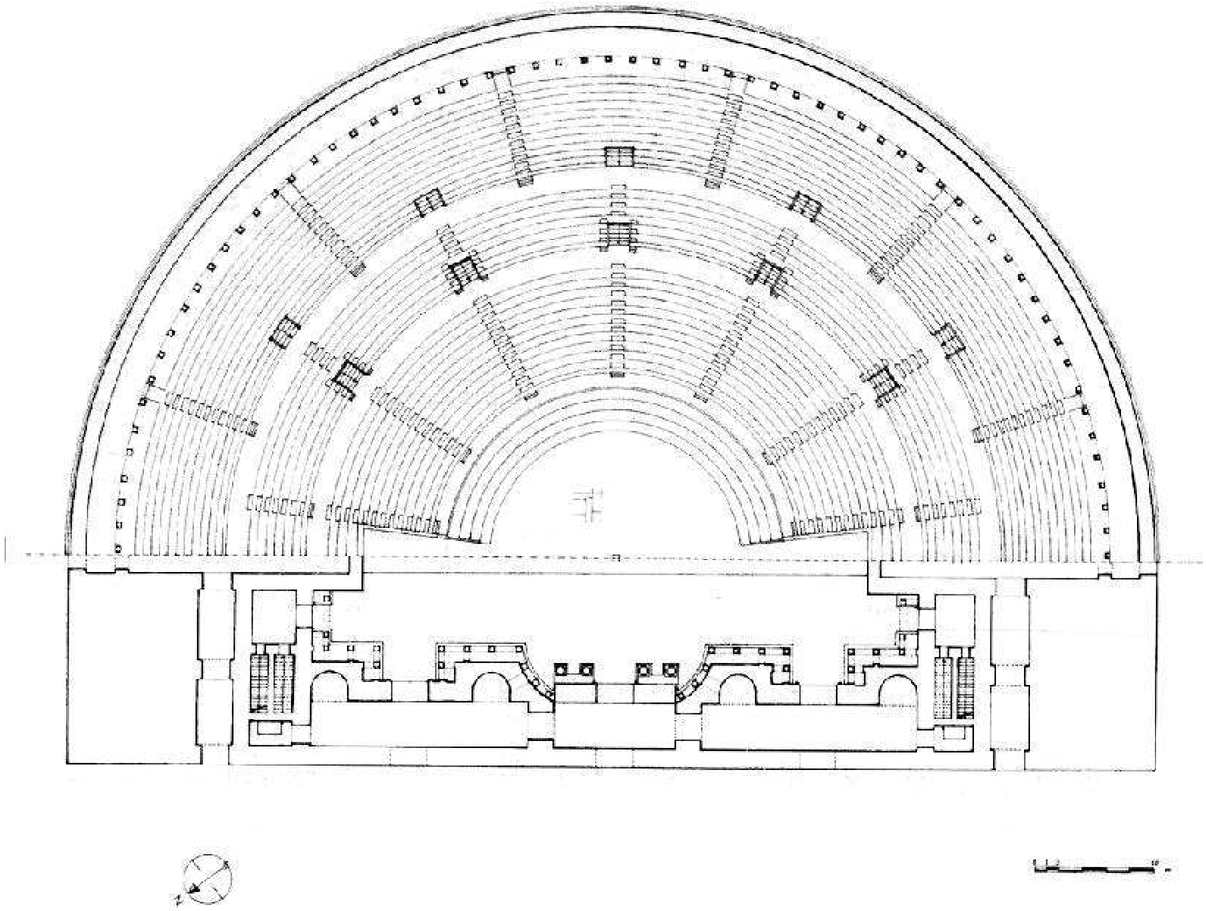

Figure 3 Reconstruction plan of the theatre at Kazinedes by Montali (with permission from the author).

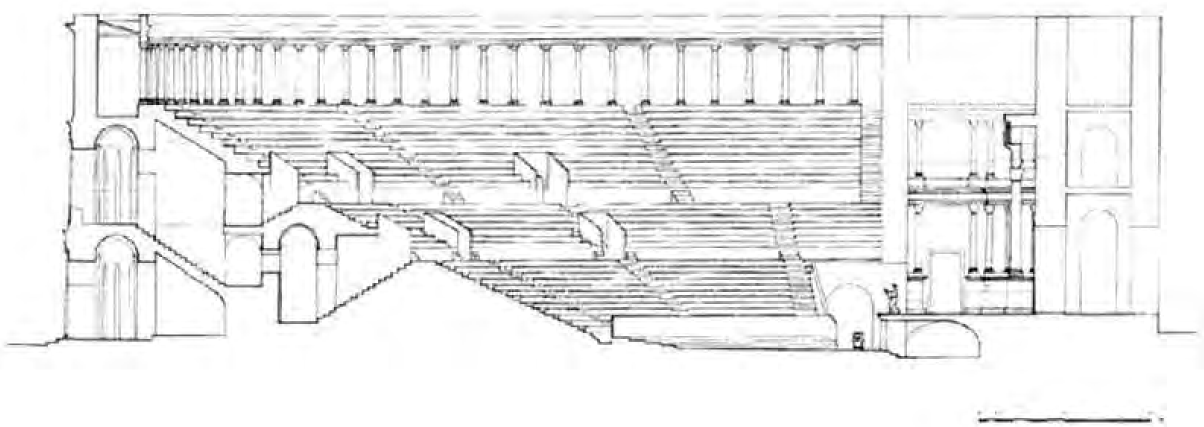

Figure 4 Reconstruction section of the theatre at Kazinedes by Montali (with permission from the author).

Speech Transmission Index (STI) establishes objectively the quality of level of spoken, calculating the combined effect of background noise and reverberation on the intelligibility of the speech. When there are no interferences on the characteristics of modulation of the signal, there are suitable conditions of intelligibility. Values of STI between 0.60 and 0.75 are good; greater than 0.75 are excellent (Spagnolo 2008).

The case study object of this research is one of the Roman theatres of Gortyna, the one identified at Kazinedes. Its remains were initially interpreted as an amphitheatre but the discovery of the latter during the 1990s suggested that the initial hypothesis about the identity of this structure should be reconsidered. It has been recognised that the shape of the remains indicates a large theatre, probably dated between the 2nd and the 3rd century AD.

This theatre has not been extensively excavated but it has been investigated through a couple of trenches and some remains are still visible (Fig. 1). Montali (2006) conducted a thorough archaeological study of this monument (Fig. 2) and proposed a reconstruction based on the available information and on comparisons with other theatres of the same period. In the proposed plan (Fig. 3), we see the cavea divided into three sectors (*ima*, *media* and *summa* cavea), with ten *vomitoria* to allow the entrance to the spectators and with a portico on the top. The *scaenae frons* has three entrances for the actors, a central semi-circular niche plus two rectangular niches on the sides, and two stories of columns. Montali also added stairwells and basilicas at the sides of the scene building. According to him, the diameter of the cavea is 91 meters and the diameter of the orchestra is 20.7 meters.

2. Methodology

Three different 3D models of this theatre have been elaborated through the software 3D Studio Max (version 2016).

1. A 3D model representing the reconstruction hypothesis by Montali (Figs. 3 and 4).
2. The first 3D model has been modified. The passages at the sides of the stage have been left open: the columns have been removed, while the stairwells and the basilicas have been moved slightly back (Fig. 5). This reconstruction hypothesis is justified by the absence of visible remains of a structure in this area, as noticeable in the satellite image taken from Google Earth and in the plan of the survey (Figs. 1 and 2).
3. The second 3D model has been further modified: the portico in summa cavea has been removed because no traces of it have been documented (Fig. 5).

All 3D models have been imported in, and analysed through, the software Odeon Room Acoustics (version 9.2 Combined) in order to obtain information about the acoustics of these possible reconstructions. The compared examination of the obtained results for each parameter indicating the acoustics' quality of a room (T60, EDT, C80, D50, STI) has allowed to establish which reconstruction is the most reliable and accurate, and therefore it permits a better knowledge of the architecture of the Roman theatre of Gortyna at Kazinedes.

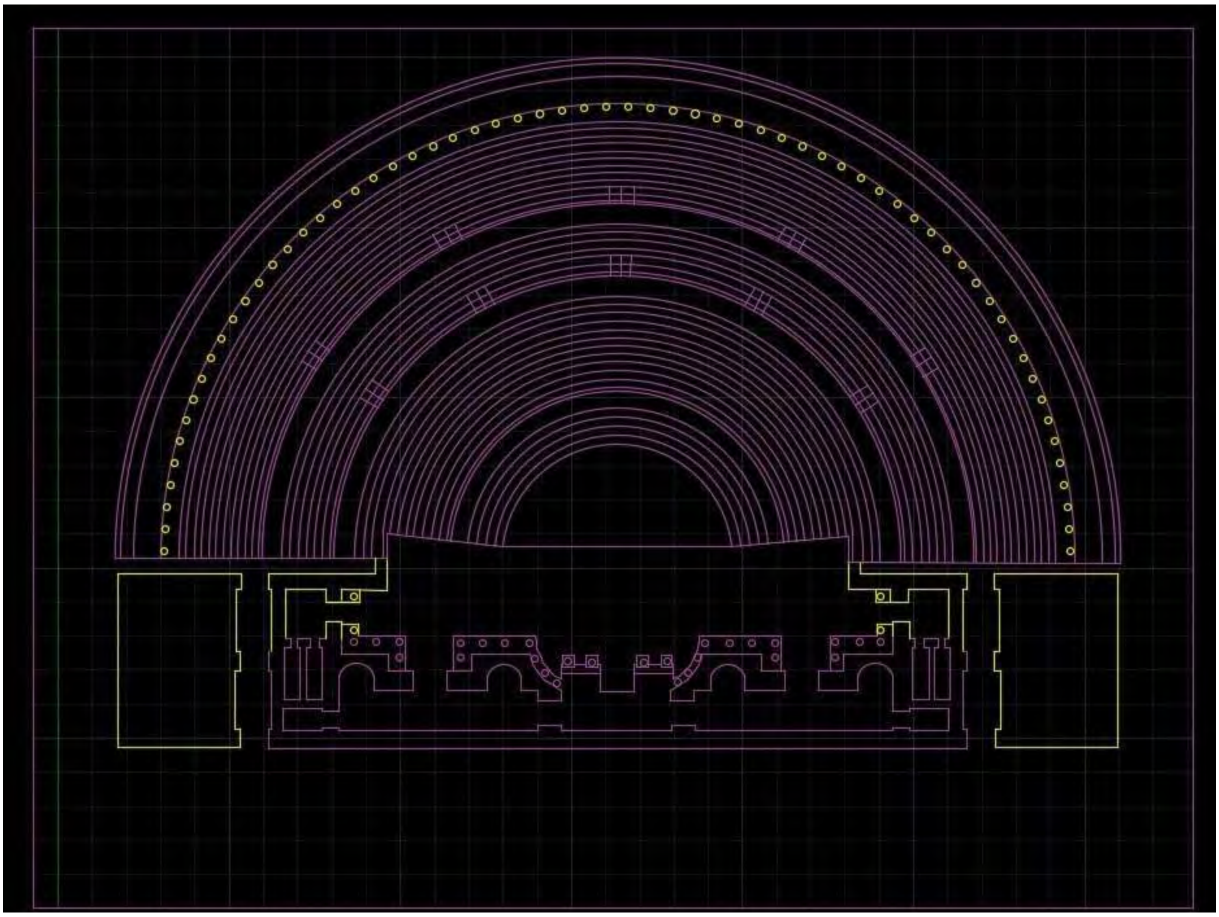

Figure 5 Representation synthesis of the hypothetical reconstruction proposed by Montali. The yellow lines indicate the architectural parts that have been modified in model numbers 2 and 3.

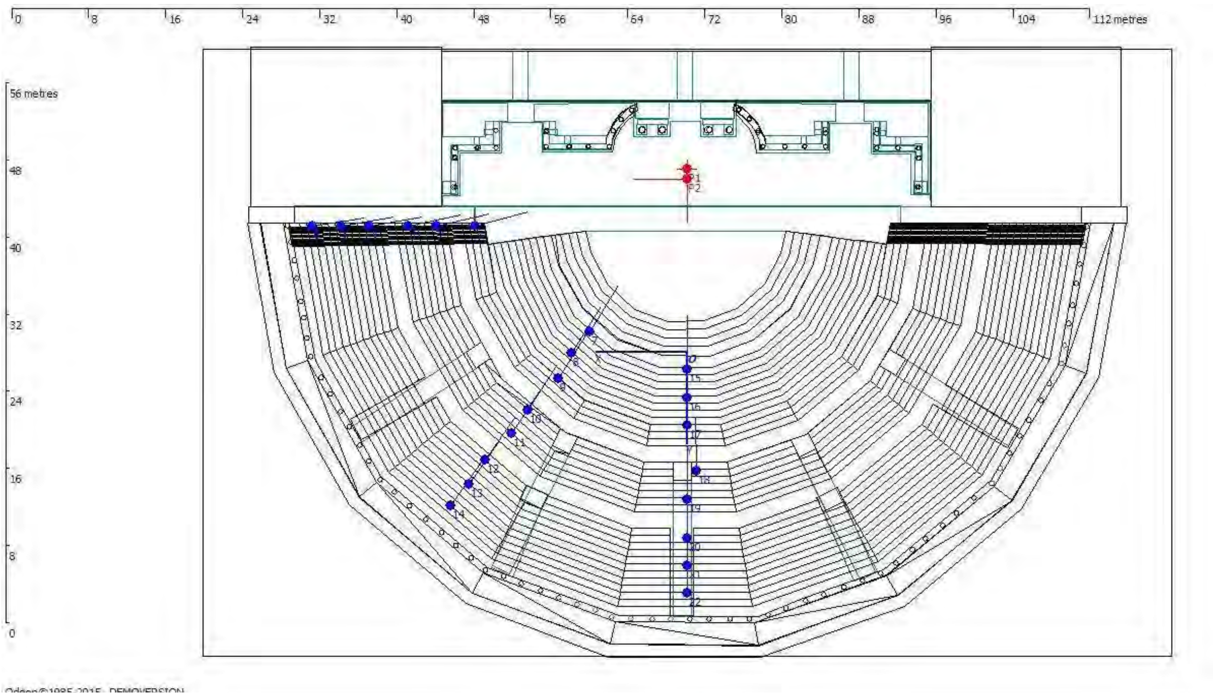

Figure 6 Plan of the 3D model number 1 of the theatre at Kazinedes, Gortyna, plus source and receivers in Odeon Room Acoustics Software.

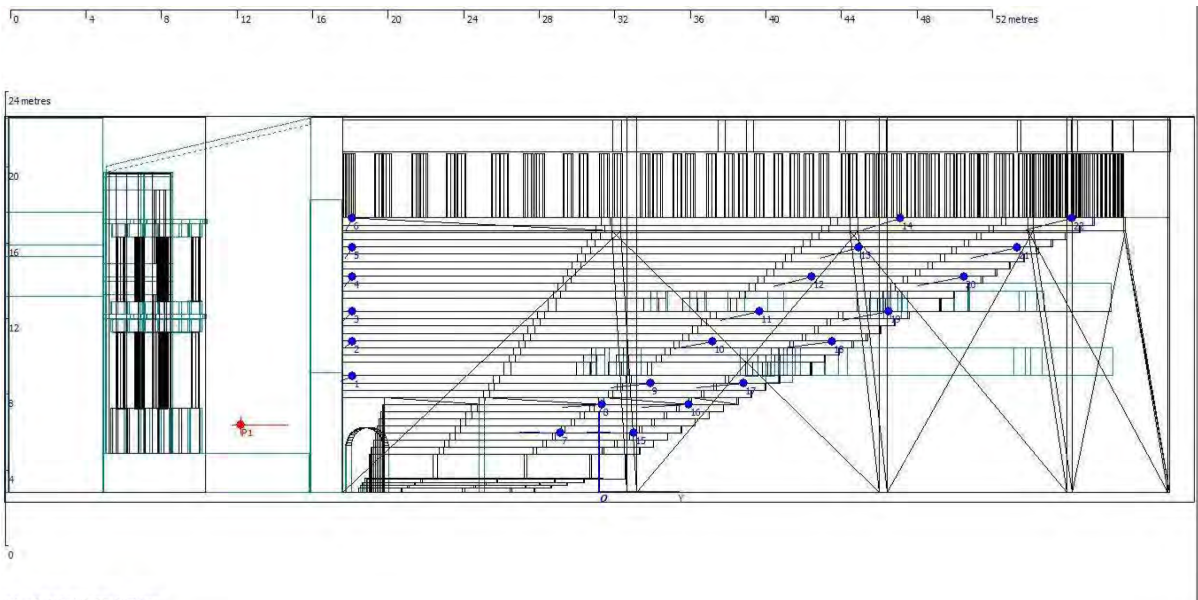

Figure 7 Section of the 3D model number 1 of the theatre at Kazinedes, Gortyna, plus source and receivers in Odeon Room Acoustics Software.

In Odeon there are important settings to be checked. First of all, a boundary box must be built all around the model, because Odeon works only with closed rooms. In order to give the effect of an open-air theatre it is important to give a total absorption to the surfaces composing the box. Then, it must be checked that the model does not have any hole, it must be watertight so as not to lose rays emitted by the source. Another fundamental step is the assignment of the correct material to each surface of the model: the absorption coefficients of the materials in the room influence much of the sound's energy that propagates in the area and, in this way, they influence the quality of the acoustics. The materials used are marble (floor of the orchestra, columns, scene building decorations), porous stone (pedestals of the scene building) and bricks (wall of the scene building and converging wall of the cavea), according to the information given by Montali.

In addition, the material "audience" has been added to the seating area in order to better simulate the acoustics during the performances. A source (representing the actor) has been placed on the stage;

22 receivers have been located in three radial rows in the seating area, covering only one half of the cavea (being symmetrical it is not necessary to put receivers also in the other half of the seating area), 75 centimetres above the surface of the seat because this should be the height of the eye level of a seated man (Figs. 6 and 7).

3. Results

Odeon measures the response of the receivers at each frequency from 63 Hz to 8000 Hz, but only the range from 125 Hz to 2000 Hz has been considered in this study because these are the frequencies understandable by the human ear. Once the results were obtained, the average values for all the receivers were calculated at each frequency, for each parameter, in order to have a clearer overview and to help in the interpretation of the data. The results are assessed with regard to the ideal values of the above-mentioned parameters (T60, EDT, C80, D50 and STI) for speech performances because the Roman theatres were generally used for this kind of exhibitions.

The tables constitute informative documents about the average values of the considered acoustics parameters. In red colour are indicated those results that exceed the recommended values. Already from the synthesis of the results which is proposed in the tables, it is possible to observe that in the first two models we have some issues with the reverberation time and with the clarity (Tabs. 1-2). Furthermore, in both models, the difference between T60 and EDT occasionally exceeds 0.4 seconds (indicated by the light blue colour in the tables). We have no anomalous values regarding model number 3 and it is also possible to observe that clarity, definition and speech transmission index have increased, a fact which indicates an improvement in the comprehension of the sound in such a context (Tab. 3). The STI is good in all reconstructions, but it is higher, and therefore better, in the third model (Tab. 4).

	T60	EDT	C80	D50
125 Hz	1.71	1.57	2.18	0.50
250 Hz	1.51	1.16	4.28	0.61
500 Hz	1.39	0.96	6.23	0.70
1000 Hz	1.32	0.89	6.43	0.71
2000 Hz	1.26	0.77	6.87	0.73

Table 1 Average values of T60, EDT, C80 and D50, obtained for the model number 1 at each frequency.

In order to better compare the three reconstructions, the overall percentage of the "not acceptable values" has been calculated for each one of them:

- Model number 1: 17%
- Model number 2: 13%
- Model number 3: 3%

It is additionally evident that the first two environments could be problematic as regards a good comprehension of the speech during a performance, while the third room has a very low percentage of "error".

	T60	EDT	C80	D50
125 Hz	1.66	1.55	2.66	0.52
250 Hz	1.5	1.08	4.57	0.61
500 Hz	1.34	0.8	6.11	0.69
1000 Hz	1.28	0.79	6.12	0.69
2000 Hz	1.18	0.76	6.4	0.70

Table 2 Average values of T60, EDT, C80 and D50, obtained for the model number 2 at each frequency.

	T60	EDT	C80	D50
125 Hz	1.34	1.12	3.83	0.61
250 Hz	1.14	0.79	6.26	0.71
500 Hz	0.93	0.66	8	0.77
1000 Hz	0.86	0.65	8.07	0.77
2000 Hz	0.82	0.73	8.37	0.77

Table 3 Average values of T60, EDT, C80 and D50, obtained for the model number 3 at each frequency.

	STI
Model 1	0.66
Model 2	0.65
Model 3	0.77

Table 4 Average values of STI for each model.

Conclusion and future works

According to the virtual acoustic analysis the hypothetical reconstruction proposed by Montali (model number 1) is not the most accurate. Reverberation time is too elevated at the low-middle frequency (125 Hz, 250 Hz and 500 Hz) for some of the receivers. This does not allow a perfectly clear comprehension of words and, more generally, of speech, since clarity and definition are too low in some seats. In addition, the difference between reverberation time and early decay time is higher than 0.4 seconds at the mid-high frequency (500 Hz, 1000 Hz and 2000 Hz) and denotes a problematic distribution of the sound.

It has been demonstrated that small changes in the structure of the scene building (model number 2) do not generate substantial improvements in the quality of the acoustics. Fewer receivers perceive a high reverberation time and consequently they have higher clarity and definition, but still many of them give altered values. Instead, the removal of the portico in summa cavea from the model number 2 (model number 3) has allowed several substantial improvements in the quality of the acoustics. The reverberation time is lower, namely around 1 second, as it should be for optimal speech performances, because of the removal of the surfaces of the portico, which create late reflections. Consequently, the values of clarity, definition and speech transmission index are higher, indicating a much better understanding of speech.

The present research has proved that virtual acoustic analysis can be useful for a deeper understanding of the architectural structure of the Roman theatre of Gortyna, at Kazinedes. Obviously, this analysis can be applied to other theatres and to other buildings reserved for performances as well. In doubtful cases, it can be also used to determine if a monument was able to host speech performances or music exhibitions. The results of this study open new questions: is virtual acoustic analysis enough to determine the architecture of destroyed monuments, or is it only a validation tool? If the present reconstruction hypothesis based on virtual acoustic analysis is correct, which theatres can be compared to it in order to know more about building techniques in the Roman Empire? Further analysis will be applied in order to verify once again the reconstruction proposed by model number 3. Such 3D visibility analysis can help the detection of architectural elements impeding the visibility of the stage from the spectators' point of view (Manzetti 2016).

Virtual acoustics analysis enhances the interpretation of monuments with few surviving remains. It adds fundamental information about those monuments where acoustics is an essential aspect, and thanks to these data, plus other basic architectural knowledge, it is possible to reconstruct a more realistic representation of theatres, odea and other buildings used for public performances. As we know, archaeology in general, and the reconstruction of monuments more in particular, require the application of several methodologies and techniques in order to achieve sound conclusions. Virtual acoustics analysis, combined both with innovative and traditional instruments, is able to push the envelope of reconstruction approaches further and produce data which are helpful enough to improve our knowledge about the missing parts of architecture of ancient buildings, and to verify the presence of porticos, windows, corridors and roof that is all these elements that influenced acoustics.

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ΨΗΦΙΑΚΗ ΑΝΑΚΑΤΑΣΚΕΥΗ ΑΓΓΕΙΩΝ ΑΒΑΦΗΣ ΚΕΡΑΜΙΚΗΣ ΜΕ ΦΩΤΟΓΡΑΜΜΕΤΡΙΑ ΚΑΙ ΤΗ ΜΕΘΟΔΟ ΔΙΑΤΟΜΗΣ ΠΑΧΟΥΣ

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Περίληψη/Abstract

Η ψηφιακή ανακατασκευή ενός θραυσμένου κεραμικού αγγείου από μια αρχαιολογική ανασκαφή, είναι ένα ανοικτό και σύνθετο πρόβλημα, το οποίο εξακολουθεί να απασχολεί έντονα την παγκόσμια επιστημονική κοινότητα. Η πλειονότητα των μέχρι σήμερα προτεινομένων μεθόδων για την ψηφιακή ανακατασκευή ενός κεραμικού αγγείου, βασίζεται κυρίως στα εξωτερικά χαρακτηριστικά των θραυσμάτων (οστράκων), τα οποία όμως επηρεάζονται σημαντικά από τη φθορά που έχουν υποστεί στο πέρασμα των αιώνων. Στην συγκεκριμένη επιστημονική εργασία, η διαδικασία της ανακατασκευής βασίζεται σε μια εντελώς νέα, διαφορετική και πιο ασφαλή ιδέα, η οποία δεν αναζητά πληροφορίες στις εξωτερικές επιφάνειες των θραυσμάτων, αλλά χρησιμοποιεί μετρήσεις πάχους από το εσωτερικό των οστράκων. Η νέα ψηφιακή μέθοδος, επαληθεύεται πειραματικά με τη χρήση τεχνολογιών αιχμής (3Δ Γραφικά) σε θραύσματα αυθεντικών αρχαίων κεραμικών αγγείων, καθώς και σε σύγχρονα, κατασκευασμένα σε τροχό, χειροποίητα αντίγραφα κεραμικών αγγείων.

The reassembly of broken archaeological ceramic pottery from its fragments (called sherds or *ostraca*) is an open and complex problem, which remains a scientific process of extreme interest for the archaeological community. All the solutions suggested by various research groups and universities so far, depend on external characteristics of sherds. All these methods suffer from problems caused by external wear and decay of the material during the exposure in soil. In our approach, the reassembly process is based on a new, different and quite fail-safe idea, since it focuses on thickness information encapsulated in the inner part of the sherds. The new digital 3D method is being verified in various case experiments, using cutting-edge technologies such as 3D representations and precise measurements on surfaces from the acquired 3D models.

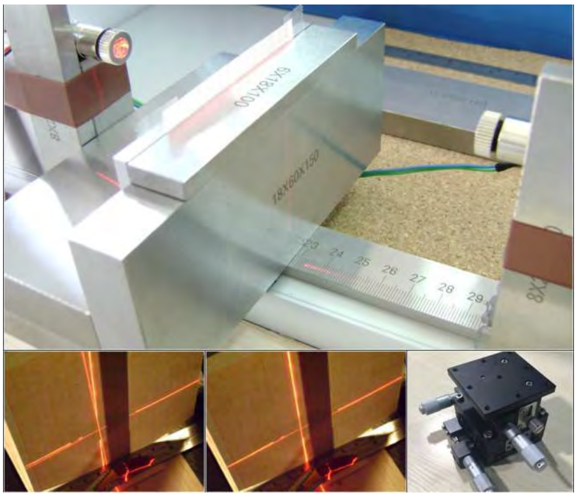
Λέξεις Κλειδιά: Διατομή πάχους, Όστρακα, Φωτογραμμετρία

Εισαγωγή

Το θέμα της ψηφιακής ανακατασκευής ενός θραυσμένου αγγείου, αρχαιολογικού ενδιαφέροντος, είναι ένα ανοικτό, σύνθετο και πολύπλευρο πρόβλημα το οποίο απασχολεί έντονα την παγκόσμια επιστημονική κοινότητα. Κάθε αρχαιολογική ανασκαφή, φέρνει ταυτόχρονα στο φως πολλές εκατοντάδες ή ακόμα και χιλιάδες μικρά κεραμικά αντικείμενα (τα λεγόμενα όστρακα), τα οποία θα προσφέρουν πλούσια ανασκαφικά συμπεράσματα αλλά κυρίως θα δώσουν την δυνατότητα στους αρχαιολόγους να χρονολογήσουν με ασφάλεια την ανασκαφή.

Είναι επίσης γνωστό ότι αυτά τα μικρά αντικείμενα, δεν απομακρύνονται από το σημείο που έπεσαν και σαν μικροί *πάπυροι,* διατηρούν επάνω τους αναλλοίωτες στο πέρασμα των αιώνων, άσβηστες, μοναδικές πληροφορίες. Η φύση αυτών των μικρών κεραμικών αντικειμένων, βάση των τεσσάρων στοιχείων που χρειάζονται για την κατασκευή τους (χώμα, νερό, φωτιά και αέρας) τους δίνει μοναδικές ιδιότητες και τα καθιστά ιδιαίτερα ανθεκτικά στο χρόνο και τη φθορά. Η αξία και το πλήθος των πληροφοριών που μεταφέρουν, χαρίζει δικαίως στα όστρακα, τον τίτλο, του *καλύτερου διακομιστή πληροφοριών* από την αρχαία εποχή έως τις ημέρες μας.

Η πλειονότητα των μεθόδων που μέχρι σήμερα προτείνονται από διάφορες ερευνητικές ομάδες και πανεπιστήμια για την ψηφιακή ανακατασκευή ενός θραυσμένου κεραμικού αγγείου (Cohen *et al.* 2010, Filippas & Georgopoulos 2013, Goldberg *et al.* 2004, Huang *et al.* 2006, Mara 2006, Karasik & Smilansky 2008, Kampel & Sablatnig 2003, Kampel *et al.* 2005, Kampel *et al.* 2006, Papaioannou *et al.* 2001, Papaodysseus *et al.* 2008, Son *et al.* 2013), βασίζονται στα εξωτερικά χαρακτηριστικά των οστράκων (γωνίες και καμπύλες στο περίγραμμα, ταίριασμα σπασμένων επιφανειών, γεωδαιτικές αποστάσεις, χρώματα, θέμα αγγείου, κ.λπ.). Όμως όλες αυτές οι τεχνικές αδυνατούν να λειτουργήσουν αποτελεσματικά στις περιπτώσεις, όπου το υλικό έχει υποστεί εξωτερικές φθορές ή απώλειες από το πέρασμα του χρόνου.

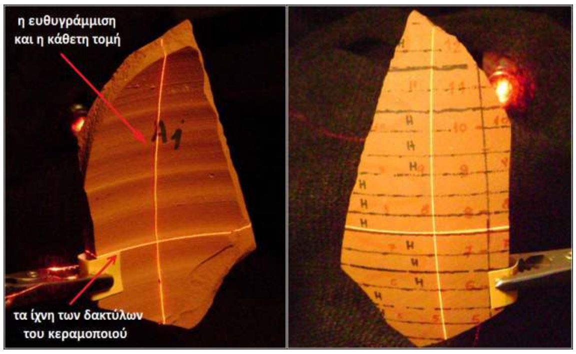


Εικόνα 1 Μέρος του εργαστηριακού εξοπλισμού.

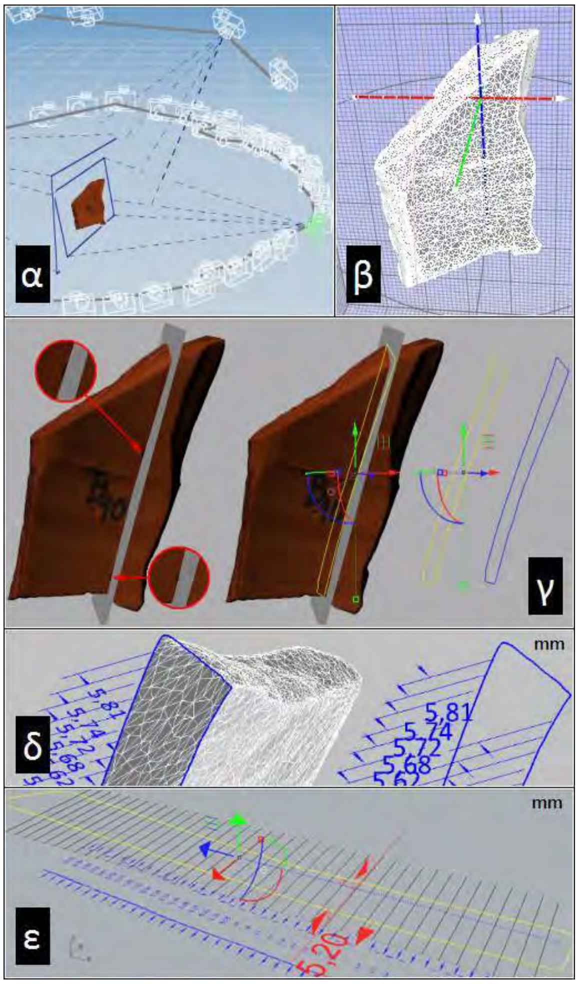
1. Η μέθοδος *Διατομής Πάχους*

Η μέθοδος που προτείνεται σε αυτήν την εργασία βασίζεται σε έναν διαφορετικό και εντελώς νέο συλλογισμό ο οποίος μπορεί να θεωρηθεί περισσότερο ασφαλής, καθώς δεν αναζητά εκμεταλλεύσιμες πληροφορίες στο εξωτερικό, επάνω ή γύρω από το όστρακο, λειτουργεί ακόμα και όταν μέρος από το υλικό του αγγείου έχει χαθεί, δεν επηρεάζεται από την παρουσία κατωφλίου φθοράς, δεν λαμβάνει υπόψη το θέμα, τα χρώματα ή τα γεωμετρικά χαρακτηριστικά του αγγείου, αλλά χρησιμοποιεί αποκλειστικά και μόνο πληροφορίες που εξακολουθούν, παρόλο το πέρασμα των αιώνων, να διατηρούνται με ασφάλεια μέσα στα όστρακα.

Η νέα μέθοδος βασίζεται στην αναζήτηση, εξαγωγή και χρησιμοποίηση όλων των πληροφοριών πάχους που μπορεί να διαθέτει στο εσωτερικό του κάθε όστρακο. Οι πληροφορίες αυτές, σαν μια συνεχόμενη ακολουθία αριθμών, μπορούν να ταξινομηθούν, να συγκριθούν και να δώσουν μια ολοκληρωμένη και ικανοποιητική λύση στο ανοικτό, περίπλοκο και πολύπλευρο πρόβλημα της ανακατασκευής ή ανασυναρμολόγησης ενός αρχαίου σπασμένου κεραμικού αγγείου που έχει διαχωριστεί σε κομμάτια, τυχαίων μεγεθών και σχημάτων. Η ιδέα βασίζεται κυρίως στο γεγονός, ότι καθώς ο κεραμοποιός περιστρέφει τον εύπλαστο πηλό στον τροχό για να δώσει σχήμα στο αγγείο, δημιουργεί παράλληλα κάποια ιδιαίτερα χαρακτηριστικά πάχους τα οποία μπορούν να ανιχνευτούν και να χρησιμοποιηθούν για την επίλυση του προβλήματος. Κάθε κατασκευή ενός κεραμικού αγγείου σε τροχό, αρχίζει από την βάση, συνεχίζει στο κυρίως σώμα και καταλήγει στο λαιμό και το χείλος (Toby 1999). Αυτή η σταδιακή και προς τα επάνω κίνηση των χεριών του κεραμοποιού, στη μάζα του πηλού, δημιουργεί μια συγκεκριμένη διατομή πάχους η οποία μπορεί να ανιχνευτεί καθώς διαφέρει με απόλυτη βεβαιότητα από σημείο σε σημείο, από ύψος σε ύψος και φυσικά από αγγείο σε αγγείο.

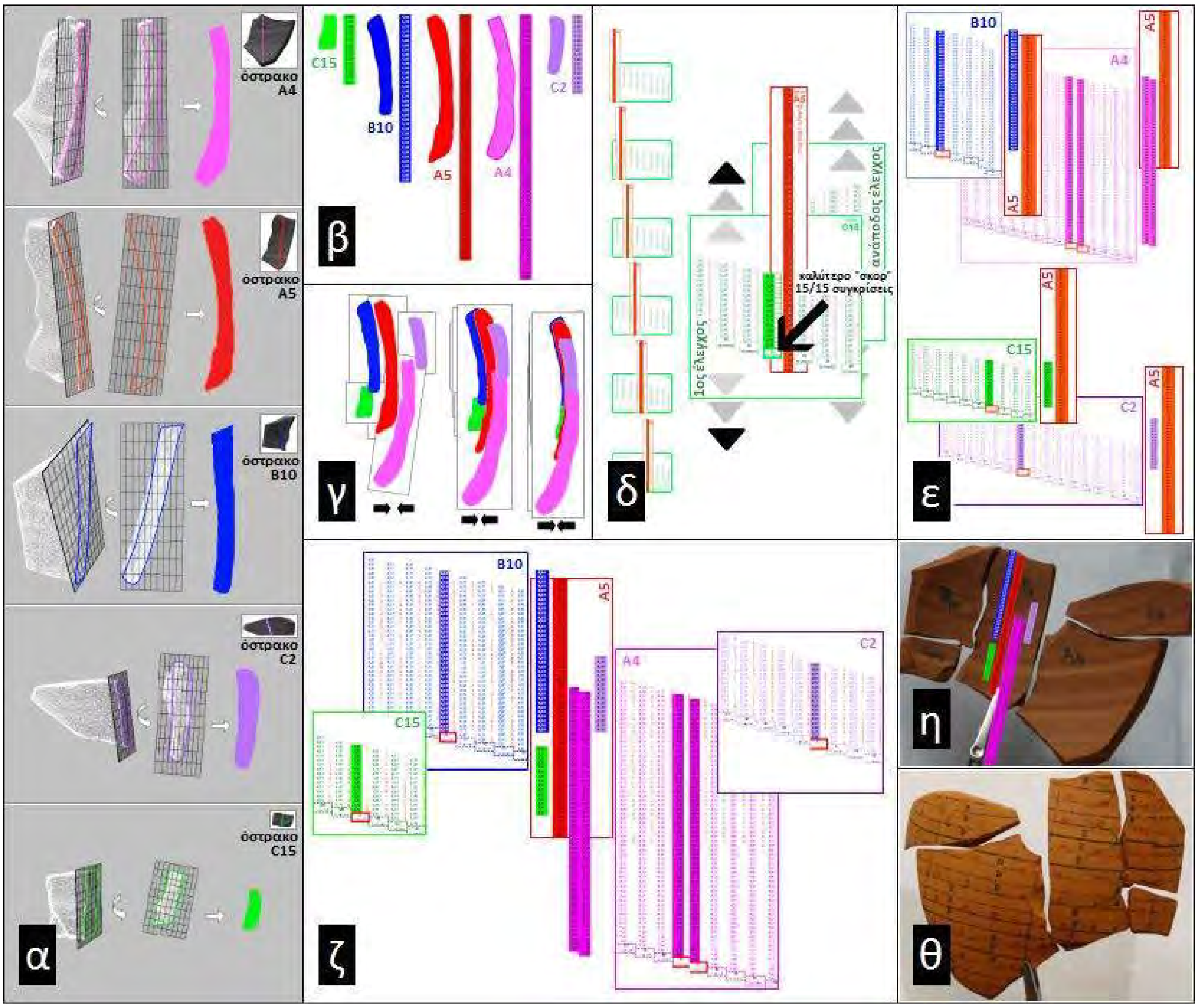


Εικόνα 2 Η ευθυγράμμιση ενός οστράκου.



Εικόνα 3 Επεξεργασία του 3Δ ψηφιακού μοντέλου.

Η διατομή αυτή δημιουργεί την εικόνα μιας δομής η οποία μοιάζει με μια στοίβα από οριζόντια δακτυλίδια, συγκεκριμένου πάχους τα οποία αυξομειώνονται σε σχέση με το ύψος του αγγείου, καθώς τα δάκτυλα του κεραμοποιού πιέζουν προς τα έξω «διαστέλλοντας» το αγγείο και άρα λεπταίνοντας τον πηλό ή αντίστοιχα, πιέζοντας προς τα μέσα «συστέλλουν» το αγγείο, κάνοντας παχύτερο τον πηλό στο σημείο αυτό. Ακριβώς σε αυτή την ιδιότητα του πηλού να αποκτά και να διατηρεί αναλλοίωτα αυτά τα δακτυλίδια πάχους βασίζεται η μέθοδος *Διατομής Πάχους* (the Thickness Profile method).



Εικόνα 4 Τα πέντε γνωστά γειτονικά όστρακα, τα βήματα της διαδικασίας και το τελικό οπτικό αποτέλεσμα. Για την πειραματική αξιολόγηση, χρησιμοποιήθηκε αντίγραφο από ένα σύγχρονο χειροποίητο κεραμικό.

Σύμφωνα με τη μέθοδο αυτή, οποιοδήποτε κομμάτι ενός σπασμένου αγγείου διαθέτει σαν αδιάψευστη σφραγίδα στο εσωτερικό του, εγκιβωτισμένες και «παγωμένες» στο χρόνο αυτές τις πληροφορίες. Εάν αυτή η στοίβα από δακτυλίδια πάχους, δημιουργεί για ολόκληρο το αγγείο κάποιες συγκεκριμένες και ολοκληρωμένες διατομές πάχους, είναι λογικό να υποθέσουμε ότι κάθε όστρακο μπορεί να ταιριάζει σε κάποιο συγκεκριμένο σημείο της στοίβας των δακτυλιδιών και άρα σε κάποιο σημείο, κάποιας συνολικής διατομής πάχους, ενός συγκεκριμένου αγγείου. Η μέθοδος εφαρμόζεται σε τρία στάδια: i) η ευθυγράμμιση (Εικόνα 2) και δημιουργία των 3Δ ψηφιακών μοντέλων από κάθε όστρακο, με μεθόδους φωτογραμμετρίας (Εικόνα 3/α), ii) η εξαγωγή της καλύτερης κάθετης τομής από τα ψηφιακά μοντέλα με κατάλληλο προσανατολισμό ενός κατακόρυφου επιπέδου (Εικόνα 3/β και Εικόνα 3/γ) και iii) η υπολογιστική διαδικασία προκειμένου να επιτευχθεί μια τοπική βέλτιστη ευθυγράμμιση από τη μεγιστοποίηση των αποτελεσμάτων ταιριάσματος μεταξύ οστράκων (Εικόνα 4/δ, Εικόνα 4/ε και Εικόνα 4/ζ).

1.α Η δημιουργία των 3Δ ψηφιακών μοντέλων

Καθώς είναι απολύτως αναγκαίο για τους αρχαιολόγους να διαφυλαχθεί η ακεραιότητα του υλικού, χρησιμοποιούμε τα 3Δ ψηφιακά αντίγραφα, εξαλείφοντας πλήρως κάθε κίνδυνο πρόκλησης βλαβών για τα ίδια τα όστρακα. Για να εφαρμόσουμε την μέθοδο αναζητάμε αρχικά σε κάθε όστρακο μια κάθετη τομή μέσω της οποίας αναμένουμε να εξάγουμε τη μεγαλύτερη δυνατή διατομή πάχους. Για το σκοπό αυτό ευθυγραμμίζουμε το κάθε όστρακο χρησιμοποιώντας μια πλάκα επιπεδότητας, ένα σετ πλακών παραλληλισμού, δύο εργαστηριακά laser και μια πλατφόρμα μικροστήριξης (Εικόνα 1). Τα δύο εργαστηριακά laser, τα οποία εκπέμπουν σε δέσμη σταυρονήματα και έχουν την δυνατότητα εστιακής ρύθμισης, τοποθετούνται αντικριστά και παραλληλίζονται έτσι ώστε τα δυο σταυρονήματα να ευθυγραμμίζονται απόλυτα στους άξονες X,Y και Z (Εικόνα 1). Το κάθε όστρακο τοποθετείται και προσανατολίζεται ανάμεσα στις δυο δέσμες σε σχέση με τα εσωτερικά οριζόντια ίχνη από τα δάκτυλα του κεραμοποιού (Εικόνα 2).

Έτσι αποκτά τρία μικρά σημάδια από μολύβι ή ειδική αυτοκόλλητη ταινία (Εικόνα 3/γ/αριστερά) που αναπαριστούν τη θέση της ιδανικής κάθετης τομής. Ακολούθως το κάθε όστρακο, τοποθετείται σε μια σταθερή βάση και φωτογραφίζεται πανοραμικά, από κοντινή απόσταση, από όλες τις πλευρές και από πολλές διαφορετικές οπτικές γωνίες (Εικόνα 3/α). Το αποτέλεσμα, για κάθε όστρακο, είναι ένα σύνολο από 30-50 φωτογραφίες το οποίο μετατρέπεται στο πιστό 3Δ ψηφιακό μοντέλο (point cloud/mesh) μέσω ενός λογισμικού φωτογραμμετρίας (Εικόνα 3/β).

1.β Η εξαγωγή των διατομών πάχους

Είναι πολύ σημαντικό από κάθε όστρακο, να ανιχνεύσουμε τη μεγαλύτερη κάθετη τομή καθώς αυτή θα μας δώσει και τις πλουσιότερες πληροφορίες πάχους (Εικόνα 3/γ/δεξιά). Μια μεγάλη διατομή πάχους θα αυξήσει, στη συνέχεια της διαδικασίας τις πιθανότητες επιτυχίας των αντιστοιχίσεων μέσω καλύτερων ταιριασμάτων. Στο στάδιο της εξαγωγής των διατομών από τα όστρακα, πραγματοποιούμε δειγματοληψίες πάχους ανά ένα χιλιοστό (Εικόνες 3/δ και 3/ε).

1.γ Η επεξεργασία των διατομών πάχους

Ακολουθώντας τα προηγούμενα στάδια και μέσω μιας υπολογιστικής διαδικασίας η μέθοδος δημιουργεί υποψήφια ταιριάσματα αναζητώντας τοπικά βέλτιστα. Διαισθητικά, αυτό αντιστοιχεί σε μια προσπάθεια να «ενσωματώσουμε» μικρές διατομές πάχους μέσα σε μεγαλύτερες διατομές πάχους. Στόχος είναι, σε όστρακα «οδηγούς» να στοιβάξουμε σταδιακά περισσότερα δακτυλίδια πάχους και άρα να δημιουργήσουμε μεγαλύτερες τοπικές διατομές πάχους, αυξάνοντας τις πιθανότητες να ταιριάξουμε και κάποια από τα υπόλοιπα όστρακα στις σωστές τους θέσεις.

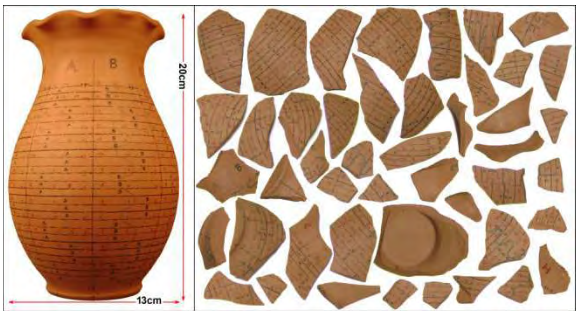
Αρχικά, τα μεγαλύτερα όστρακα αποκτούν τον ρόλο του «οδηγού» και καθώς η διαδικασία θα προχωρά, τα όστρακα «οδηγοί» θα αποκτούν περισσότερα δακτυλίδια πάχους και άρα περισσότερα κομμάτια θα ταιριάζουν μεταξύ τους δημιουργώντας ενιαία μετα-όστρακα, από τις αυξανόμενες διατομές πάχους (Εικόνα 4/γ). Η αναζήτηση του ιδανικά καλύτερου υποθετικού ταιριάσματος θα μπορούσε να βρεθεί μόνο στην περίπτωση που δύο διατομές πάχους ταίριαζαν απόλυτα μεταξύ τους και η ακολουθία αριθμών, ενός μικρού οστράκου βρισκόταν ακριβώς (αυτούσια) κάπου μέσα, στην ακολουθία των αριθμών ενός μεγαλύτερου οστράκου. Η απόλυτη αυτή ταύτιση θα ήταν δυνατή μόνο σε μια ιδανική περίπτωση και όχι σε πραγματικά δεδομένα. Άλλωστε η μέθοδος βασίζεται περισσότερο στο πλήθος των μετρήσεων και λιγότερο στην ακρίβεια των μετρήσεων. Ως εκ τούτου, η διαδικασία αναζητά την επίτευξη του καλύτερου «σκορ», με τις λιγότερες διαφορές στις περισσότερες δυνατές συγκρίσεις.

Καλύτερο «σκορ» ορίζεται το άθροισμα των απολύτων διαφορών, ανάμεσα στις περισσότερες δυνατές συγκρίσεις πάχους μεταξύ δύο οστράκων. Στο σημείο που έχουμε το καλύτερο αποτέλεσμα, μπορούμε να συμπεράνουμε ότι βρισκόμαστε σε ταίριασμα. Η μέθοδος *Διατομής Πάχους*, είναι μια ημιαυτόματη μέθοδος καθώς δεν μπορεί να αποφασίσει, κατά το ταίριασμα δύο οστράκων, ποιο θα τοποθετηθεί αριστερά και ποιο θα τοποθετηθεί δεξιά. Στο σημείο αυτό το έμπειρο μάτι του αρχαιολόγου θα πρέπει να δώσει την λύση της αριστερής ή δεξιάς τοποθέτησης.

Επιπλέον, τα πολύ μικρά όστρακα, τα οποία δεν μπορούν να δώσουν μεγάλες τομές, αυξάνουν την πιθανότητα να προταθούν για τοποθέτηση σε λάθος σημείο. Η μέθοδος *Διατομής Πάχους*, λειτουργεί καλύτερα σε κεραμικά αγγεία τα οποία κατασκευάστηκαν σε νεότερες αρχαιολογικές περιόδους (αρχαϊκή, κλασική ή ελληνιστική εποχή) καθώς τα αγγεία αυτά, διαθέτουν εκλεπτυσμένα χαρακτηριστικά (καλύτεροι τροχοί, ποιότητα πηλού, καλύτερο ψήσιμο, κ.λπ.) και οι πληροφορίες πάχους είναι εύκολα διακριτές, διατηρούνται και μπορούν να αξιοποιηθούν από τη μέθοδο.

2. Πειραματική αξιολόγηση

Για την πειραματική αξιολόγηση, χρησιμοποιήθηκε αντίγραφο από ένα σύγχρονο χειροποίητο κεραμικό αγγείο κατασκευασμένο σε τροχό (Εικόνα 5). Το αγγείο αυτό έσπασε σε 46 κομμάτια και το σύνολο του υλικού που προέκυψε και μπορούσε να αξιοποιηθεί (34 όστρακα), ανασυναρμολογήθηκε ψηφιακά με τη μέθοδο *Διατομής Πάχους*. Το αγγείο αρχικά προετοιμάστηκε, με κατάλληλη σήμανση, ώστε στη συνέχεια να είναι δυνατό να επιβεβαιωθούν τα αποτελέσματα μας. Ειδικότερα, σχεδιάστηκαν στην εξωτερική του επιφάνεια υψομετρικές κυκλικές τροχιές (ανά 0.5 cm) και επιπλέον διαχωρίστηκε σε 8 κάθετες χρωματικές περιοχές (A, B, C, D, E, F, G και H) στις 45, 90, 135, 180, 225, 270, 315 και 360 μοίρες αντίστοιχα. Το αγγείο είχε ύψος 20 cm, μέγιστη εξωτερική περιφέρεια 42 cm και ζύγιζε 800 γραμμάρια.



Εικόνα 5 Το κεραμικό αντίγραφο. Δεξιά, τα 46 κομμάτια που προέκυψαν μετά από το σπάσιμο του.

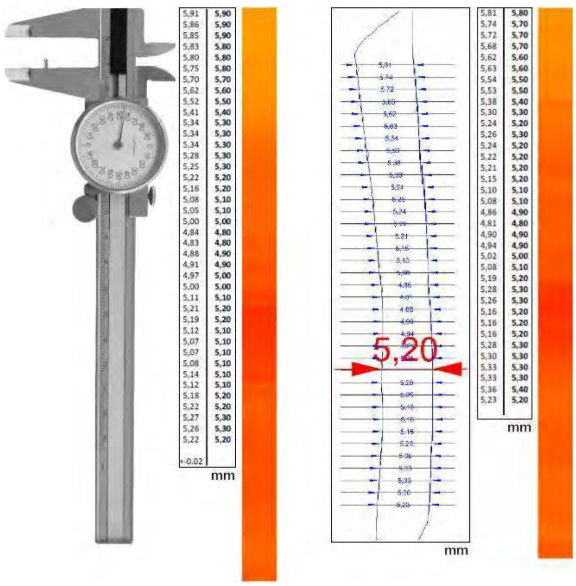
2.α Η επίδειξη της μεθόδου

Για την επίδειξη και για χάρη της απλότητας χρησιμοποιήσαμε από το συγκεκριμένο αγγείο πέντε γνωστά γειτονικά όστρακα (A4, A5, B10, C2 και C15). Στην Εικόνα 4/α, παρουσιάζονται τα 3Δ μοντέλα των πέντε οστράκων και η διαδικασία της εξαγωγής των βέλτιστων καθέτων τομών. Με το κατάλληλο cad λογισμικό εκτελέσθηκε από κάθε 3Δ ψηφιακή τομή, δειγματοληψία πάχους ανά ένα 1mm και δημιουργήθηκαν οι πέντε διατομές πάχους (Εικόνα 4/β).

Ακολούθως, με την διαδικασία που αναλύθηκε στην ενότητα 1.γ (Εικόνες 4/γ και 4/δ), η μέθοδος επέτρεψε την ακριβή συναρμολόγηση των πέντε όστρακων με την ελάχιστη ανθρώπινη παρέμβαση. Στις Εικόνες 4/ε και 4/ζ, παρουσιάζεται η αποτελεσματική αντιστοίχιση αυτών των πέντε συγκεκριμένων διατομών πάχους ως ένα ταίριασμα ακολουθιών και στην Εικόνα 4/η το ίδιο αποτέλεσμα ως μια οπτική άποψη από την εσωτερική πλευρά των οστράκων με τις διατομές πάχους σχεδιασμένες επάνω στις εσωτερικές τους επιφάνειες. Στην Εικόνα 4/θ, παρουσιάζεται η επιτυχής συνένωση του υλικού από την αντίστοιχη εξωτερική επιφάνεια.

2.β Ακρίβεια μετρήσεων και το ειδικό λογισμικό

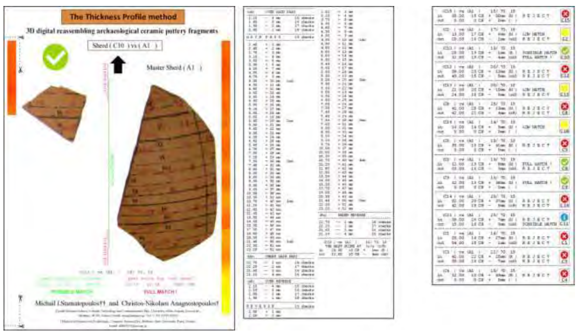
Ένα κρίσιμο σημείο για την επιτυχή εφαρμογή της μεθόδου από τον ερευνητή, είναι η ακρίβεια στο πάχος που μπορεί να ανακτηθεί (Gomez-Gutierrez *et al.* 2014) από τα διαθέσιμα όστρακα. Το μέσο μέγεθος πάχους των οστράκων, κυμαίνεται συνήθως μεταξύ 2-15 mm. Τα όρια αυτά επιβεβαιώθηκαν σε όλα τα όστρακα που παρουσιάζονται ως μεμονωμένα εκθέματα στο Εθνικό Αρχαιολογικό Μουσείο της Αθήνας.



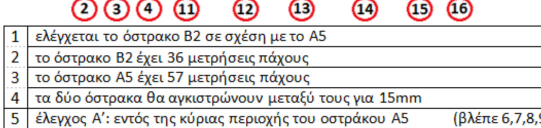
Εικόνα 6 Η διακρίβωση της διακριτικής ικανότητας.

Η μέθοδος *Διατομής Πάχους,* απαιτεί ικανότητες διάκρισης σε εκατοστά του χιλιοστού (0.01 mm). Για την παρουσίαση και την απόδειξη της απαιτούμενης διακριτικής ικανότητας, χρησιμοποιήσαμε ένα παχύμετρο (το όργανο ακριβείας των αρχαιολόγων), με στόχο να συγκρίνουμε τις μετρήσεις του οργάνου, με τις μετρήσεις που είχαμε αποκτήσει από την ψηφιακή επεξεργασία με τη φωτογραμμετρία και τα vector λογισμικά. Ειδικότερα το όστρακο B10, μετρήθηκε με το παχύμετρο και τα δεδομένα συγκρίθηκαν με τις ψηφιακές μετρήσεις.

Τα συγκριτικά αποτελέσματα παρουσιάζονται στην Εικόνα 6. Στην αριστερή πλευρά οι μετρήσεις με το παχύμετρο και δεξιά με την φωτογραμμετρία. Στα δύο αντίστοιχα άκρα, απεικονίζονται με χρωματικές κλίμακες οι μετρήσεις, απόλυτα διακριτές και σχεδόν ταυτόσημες. Για την επεξεργασία των μετρήσεων πάχους, αναπτύξαμε ειδικό λογισμικό το οποίο εκτελεί τις συγκρίσεις (σε δέκατα του χιλιοστού 0.1 mm) και εξάγει τα συμπεράσματα. Για κάθε ζευγάρι οστράκων, το λογισμικό παράγει τεχνικές εκθέσεις δύο σελίδων (Εικόνα 7), με όλες τις απαραίτητες πληροφορίες για την καθοδήγηση του αρχαιολόγου (μία από τις δύο σελίδες με γραφικά). Υποδεικνύεται η ακριβής θέση τοποθέτησης και η ανθρώπινη παρέμβαση αφορά την απόφαση για το εάν, το ελεγχόμενο όστρακο θα τοποθετηθεί αριστερά ή δεξιά σε σχέση με το όστρακο «οδηγό».

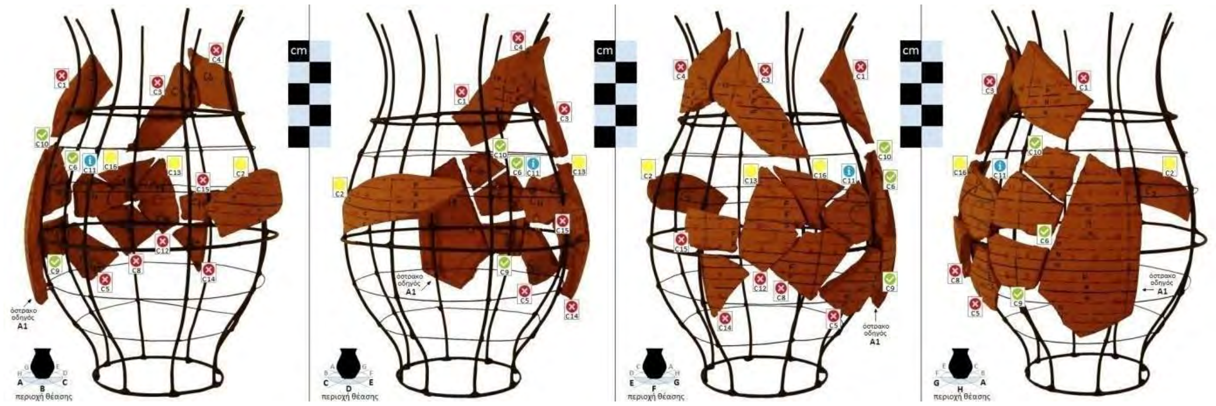


Εικόνα 7 Οι τεχνικές εκθέσεις του λογισμικού.



1	ελέγχεται το όστρακο B2 σε σχέση με το A5
2	το όστρακο B2 έχει 36 μετρήσεις πάχους
3	το όστρακο A5 έχει 57 μετρήσεις πάχους
4	τα δύο όστρακα θα αγκιστρώνουν μεταξύ τους για 15mm
5	έλεγχος Α': εντός της κύριας περιοχής του οστράκου A5 (βλέπε 6,7,8,9,10)
6	το καλύτερο "σκορ" ήταν 148
7	για 36 συγκρίσεις πάχους
8	τοποθετείστε το όστρακο B2, 22mm κάτω από την 1η μέτρηση πάχους του A5
9	αλλά, γυρίστε το B2 ανάποδα (δηλ. αναποδογυρίστε το) σε σχέση με την αρχική ευθυγράμμιση και το σημείο που έγινε η 1η μέτρηση πάχους στο B2
10	ΑΠΟΡΡΙΨΗ (ο έλεγχος Α' απορρίπτει τη σχέση)
11	έλεγχος Β': εκτός της κύριας περιοχής του οστράκου A5, αλλά με την αγκίστρωση των 15mm (βλέπε 12,13,14,15,16)
12	το καλύτερο "σκορ" ήταν 15
13	για 15 συγκρίσεις πάχους
14	τοποθετείστε το όστρακο B2, 21mm επάνω από την 1η μέτρηση πάχους του A5
15	και όπως αρχικά ευθυγραμμίσατε το όστρακο B2 αλλά βγάλτε το έξω (από την επάνω πλευρά) της κύριας περιοχής του A5
16	ΤΑΙΡΙΑΣΜΑ (ο έλεγχος Β' έδωσε "σκορ" 15/15)

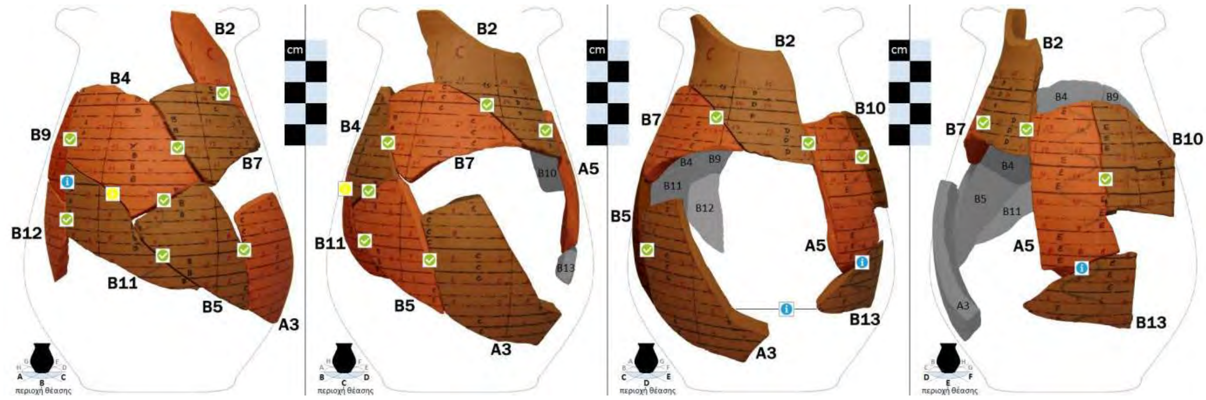
Εικόνα 8 Η επεξήγηση πληροφοριών ταιριάσματος.



Εικόνα 9 Το τελικό οπτικό αποτέλεσμα από το πείραμα, «*οι Νάνοι και ο Γίγαντας*».

ζευγάρι	σκορ & προτεινόμενη θέση	σχόλιο
(C15) vs (A1) 15/ 70, 15	εντός 35,00/15 CH +30mm (M) εκτός 0,00 / 0 CH	ΑΠΟΡΡΙΨΗ
(C2) vs (A1) 17/ 70, 15	εντός 19,00/17 CH +6mm (M) εκτός 20,00/16 CH -1mm (oM)	ΕΛΑΧΙΣΤΑ ΠΙΘΑΝΟ ΑΠΟΡΡΙΨΗ
(C10) vs (A1) 19/ 70, 15	εντός 20,00/19 CH +1mm (R) εκτός 12,00/15 CH -4mm (oM)	ΠΟΛΥ ΠΙΘΑΝΟ ΤΑΙΡΙΑΣΜΑ !
(C12) vs (A1) 20/ 70, 15	εντός 38,00/20 CH +13mm (M) εκτός 49,00/15 CH -5mm (oM)	ΑΠΟΡΡΙΨΗ ΑΠΟΡΡΙΨΗ
(C13) vs (A1) 20/ 70, 15	εντός 22,00/20 CH +10mm (M) εκτός 24,00/15 CH -5mm (oM)	ΕΛΑΧΙΣΤΑ ΠΙΘΑΝΟ ΑΠΟΡΡΙΨΗ
(C8) vs (A1) 25/ 70, 15	εντός 41,00/25 CH +19mm (M) εκτός 42,00/21 CH -4mm (oR)	ΑΠΟΡΡΙΨΗ ΑΠΟΡΡΙΨΗ
(C16) vs (A1) 14/ 70, 15	εντός 16,00/14 CH +5mm (M) εκτός 0,00 / 0 CH	ΕΛΑΧΙΣΤΑ ΠΙΘΑΝΟ
(C5) vs (A1) 15/ 70, 15	εντός 33,00/15 CH +41mm (M) εκτός 0,00 / 0 CH	ΑΠΟΡΡΙΨΗ
(C6) vs (A1) 19/ 70, 15	εντός 12,00/19 CH +8mm (M) εκτός 33,00/16 CH -3mm (oM)	ΤΑΙΡΙΑΣΜΑ ! ΑΠΟΡΡΙΨΗ
(C9) vs (A1) 13/ 70, 15	εντός 12,00/13 CH +38mm (M) εκτός 0,00 / 0 CH	ΤΑΙΡΙΑΣΜΑ !
(C14) vs (A1) 20/ 70, 15	εντός 52,00/20 CH +37mm (M) εκτός 42,00/15 CH -5mm (oR)	ΑΠΟΡΡΙΨΗ ΑΠΟΡΡΙΨΗ
(C11) vs (A1) 25/ 70, 15	εντός 35,00/25 CH +7mm (M) εκτός 15,00/16 CH -9mm (oM)	ΑΠΟΡΡΙΨΗ ΠΟΛΥ ΠΙΘΑΝΟ
(C1) vs (A1) 16/ 70, 15	εντός 20,00/16 CH +27mm (M) εκτός 54,00/15 CH -1mm (oM)	ΑΠΟΡΡΙΨΗ ΑΠΟΡΡΙΨΗ
(C3) vs (A1) 22/ 70, 15	εντός 41,00/22 CH +25mm (R) εκτός 50,00/15 CH -7mm (oM)	ΑΠΟΡΡΙΨΗ ΑΠΟΡΡΙΨΗ
(C4) vs (A1) 10/ 70, 15	εντός 12,00/10 CH +49mm (R) εκτός 0,00 / 0 CH	ΑΠΟΡΡΙΨΗ

Πίνακας 1 Τα συγκεντρωτικά αποτελέσματα του λογισμικού, για τα 16 (15+1) όστρακα.



Εικόνα 10 Το οπτικό αποτέλεσμα από την ανακατασκευή των πλευρικών τοιχωμάτων του αγγείου.

ζευγάρι	σκορ & προτεινόμενη θέση	σχόλιο
(B2) vs (A5) 36/ 57, 15	εντός 148,00/36 CH +22mm (R) εκτός 15,00/15 CH -21mm (oM)	ΑΠΟΡΡΙΨΗ ΤΑΙΡΙΑΣΜΑ !
(B5) vs (A3) 37/ 49, 15	εντός 85,00/37 CH +1mm (M) εκτός 42,00/35 CH -2mm (oM)	ΑΠΟΡΡΙΨΗ ΤΑΙΡΙΑΣΜΑ !
(B5) vs (B4) 37/ 42, 15	εντός 165,00/37 CH +1mm (R) εκτός 33,00/36 CH -26mm (Mu)	ΑΠΟΡΡΙΨΗ ΤΑΙΡΙΑΣΜΑ !
(B7) vs (B4) 31/ 42, 15	εντός 58,00/31 CH +1mm (M) εκτός 14,00/25 CH -6mm (oM)	ΑΠΟΡΡΙΨΗ ΤΑΙΡΙΑΣΜΑ !
(B7) vs (B2) 31/ 36, 15	εντός 75,00/31 CH +6mm (M) εκτός 15,00/30 CH -13mm (Mu)	ΑΠΟΡΡΙΨΗ ΤΑΙΡΙΑΣΜΑ !
(B9) vs (B4) 27/ 42, 15	εντός 12,00/27 CH +3mm (M) εκτός 30,00/26 CH -1mm (oM)	ΤΑΙΡΙΑΣΜΑ ! ΤΑΙΡΙΑΣΜΑ !
(B10) vs (A5) 36/ 57, 15	εντός 43,00/36 CH +1mm (M) εκτός 37,00/34 CH -2mm (oM)	ΤΑΙΡΙΑΣΜΑ ! ΤΑΙΡΙΑΣΜΑ !
(B11) vs (B4) 27/ 42, 15	εντός 39,00/27 CH +14mm (R) εκτός 36,00/26 CH -28mm (Mu)	ΕΛΑΧΙΣΤΑ ΠΙΘΑΝΟ ΕΛΑΧΙΣΤΑ ΠΙΘΑΝΟ
(B11) vs (B12) 27/ 35, 15	εντός 46,00/27 CH +5mm (R) εκτός 19,00/21 CH -6mm (oR)	ΑΠΟΡΡΙΨΗ ΤΑΙΡΙΑΣΜΑ !
(B11) vs (B5) 27/ 37, 15	εντός 78,00/27 CH +1mm (R) εκτός 20,00/17 CH -10mm (oR)	ΑΠΟΡΡΙΨΗ ΤΑΙΡΙΑΣΜΑ !
(B13) vs (A5) 28/ 57, 10	εντός 159,00/28 CH +28mm (M) εκτός 33,00/27 CH -48mm (Mu)	ΑΠΟΡΡΙΨΗ ΠΟΛΥ ΠΙΘΑΝΟ
(B13) vs (A3) 28/ 49, 15	εντός 34,00/28 CH +12mm (M) εκτός 72,00/22 CH -6mm (oR)	ΠΟΛΥ ΠΙΘΑΝΟ ΑΠΟΡΡΙΨΗ
(B9) vs (A1) 27/ 70, 15	εντός 46,00/27 CH +6mm (R) εκτός 13,00/15 CH -12mm (oM)	ΑΠΟΡΡΙΨΗ ΤΑΙΡΙΑΣΜΑ !
(B11) vs (B9) 27/ 27, 15	εντός 69,00/27 CH +1mm (M) εκτός 33,00/26 CH -12mm (Mu)	ΑΠΟΡΡΙΨΗ ΠΟΛΥ ΠΙΘΑΝΟ
(B12) vs (A1) 35/ 70, 15	εντός 37,00/35 CH +20mm (M) εκτός 23,00/17 CH -18mm (oR)	ΤΑΙΡΙΑΣΜΑ ! ΠΟΛΥ ΠΙΘΑΝΟ

Πίνακας 2 Τα συγκεντρωτικά αποτελέσματα του λογισμικού, για τα πλευρικά όστρακα.

A1	A2	A3	A4	A5
5,27	5,54	5,17	5,44	5,94
5,35	5,62	5,10	5,56	5,94
5,32	5,66	5,33	5,41	5,86
5,25	5,54	5,83	5,44	5,80
5,24	5,40	5,92	5,28	5,74
5,23	5,30	5,96	5,34	5,73
5,12	5,21	5,98	5,34	5,62
5,11	5,25	5,98	5,46	5,46
5,08	5,38	5,83	5,56	5,42
5,14	5,90	5,64	5,36	5,38
5,20	6,08	5,55	5,34	5,32
5,22	6,04	5,48	6,33	5,23
5,28	6,03	5,33	5,38	5,13
5,39	5,98	5,33	5,44	5,01
5,51	5,92	5,38	5,40	4,97
5,41	5,88	5,58	5,40	4,83
5,34	5,88	5,63	5,33	4,77
5,32	6,01	5,59	5,26	4,81
5,38	6,36	5,48	5,06	4,88
5,45	6,48	5,28	4,99	4,95
5,48	6,60	5,16	5,12	5,01
5,50	6,63	5,18	5,80	5,12
5,53	6,68	5,90	6,07	5,24
5,57	6,73	5,99	5,98	5,22
5,52	6,83	6,09	5,91	5,14
5,43	6,85	6,15	5,88	5,10
5,32	6,88	6,16	5,80	5,11
5,26	6,93	6,18	5,70	5,18
5,25	7,01	6,15	5,56	5,32
5,25	7,58	6,15	5,56	5,30
5,44	8,01	6,18	5,46	5,28
5,70	8,29	6,25	5,37	5,30
5,73	8,32	6,48	5,31	5,32
5,57	8,58	6,70	5,37	5,28
5,43	8,76	6,97	5,50	5,34
5,38	9,05	7,04	5,57	5,21
5,34	9,27	7,03	5,61	5,24
5,46	9,43	7,08	5,36	5,27
5,63	9,56	7,08	5,21	5,25
5,82	9,69	7,14	5,14	5,26
5,86	9,88	7,17	5,16	5,28
5,82	10,06	7,14	5,86	5,20
5.75	10.29	7.18	6.04	5.06
5.59	10.66	7.20	6.01	5.01
5,49	10,84	7,62	6,13	5.08
5.36	10.88	7.90	6.18	5.52
5,29	10,86	8,08	6,16	5,83
5,37	10,80	8,38	6,16	6,07
5,76	10,89	8,48	6,18	5,99
6,00	11,58		6,16	5,96
5,99	12,28		6,20	5,86
5,96	12,53		6,26	5,66
5,93			6,34	5,54
5,80			6,74	5,39
5,74			6,94	5,33
5,72			7,08	5,32
5,79			7,13	5,32
6,00			7,23	
6,33			7,56	
6,52			7,58	
6,63			7,62	
6,69				
6,73				
6,78				
6,83				
6,83				
6,87				
6,85				
6,88				
6,94			mm	

B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	-
10,16	5,16	7,28	5,92	5,26	8,83	5,91	4,87	5,94	5,81	5,72	5,44	5,38	7,10	
10,68	5,34	7,53	5,92	5,21	8,44	5,99	4,91	5,96	5,74	5,54	5,49	5,29	7,12	
10,98	5,44	7,76	5,88	5,03	8,27	6,04	4,98	5,90	5,72	5,35	5,52	5,30	7,14	
11,28	5,53	8,17	5,92	5,01	7,95	6,00	5,02	5,88	5,68	5,30	5,50	5,32	7,23	
	5,61	8,42	5,98	5,11	7,69	6,00	5,09	5,82	5,62	5,35	5,44	5,50	7,33	
	5,61	8,56	5,98	5,21	7,48	6,02	5,12	5,74	5,63	5,48	5,27	5,54	7,38	
	5,64	8,87	5,87	5,82	7,42	6,02	5,12	5,66	5,54	5,58	5,18	5,56	7,44	
	5,67	9,05	5,81	5,85	7,31	6,02	5,14	5,63	5,53	5,70	5,12	5,34	7,50	
	5,69	9,48	5,72	5,87	7,28	6,00	5,19	5,66	5,38	5,77	5,16	5,22	7,54	
	5,72	9,60	5,72	5,86	7,25	6,00	5,24	5,64	5,30	5,81	5,15	5,19	7,91	
	5,74	9,70	5,66	5,78	7,18	6,00	5,27	5,54	5,24	5,63	5,24	5,24	8,18	
	5,80	9,80	5,56	5,68	6,96	5,99	5,31	5,46	5,26	5,23	5,63	5,67	8,48	
	5,84	9,96	5,50	5,58	6,74	5,99	5,38	5,38	5,24	5,16	5,70	5,94	8,78	
	5,86	10,08	5,45	5,47	6,46	5,94	5,44	5,35	5,22	5,12	5,65	6,09	8,86	
	5,92	10,42	5,43	5,41	6,38	5,78	5,50	5,27	5,21	5,10	5,53	6,19	9,01	
	5,96	10,72	5,35	5,45	6,35	5,64	5,51	5,30	5,15	5,28	5,42	6,31	9,34	
	6,06	10,88	5,30	5,55	6,36	5,61	5,61	5,24	5,10	5,41	5,31	6,30	9,58	
	6,06	10,95	5,21	5,68	6,35	5,62	5,64	5,19	5,08	5,53	5,27	6,30	9,81	
	6,06	10,98	5,28	5,87	6,30	5,60	5,68	5,22	4,86	5,53	5,29	6,32	9,86	
	6,07	11,06	5,19	5,77	6,30	5,50	5,73	5,23	4,81	5,54	5,48	6,33	9,88	
	6,00	11,12	5,14	5,62	6,24	5,40	5,81	5,23	4,90	5,52	5,66	6,36	9,95	
	5,98	11,28	5,16	5,42	6,20	5,36	5,81	5,24	4,94	5,44	5,75	6,35	10,02	
	5,91	11,68	5,20	5,38	6,20	5,26	5,80	5,19	5,02	5,36	5,77	6,35	10,07	
	5,88	12,08	5,20	5,43	6,13	5,20	5,78	5,16	5,08	5,34	5,66	6,41	10,76	
	5,84	12,38	5,21	6,09		5,14	5,77	5,11	5,19	5,36	5,58	6,61	10,97	
	5,78	12,78	5,24	6,20		5,14	5,75	5,13	5,28	5,48	5,41	6,79	11,22	
	5,71	13,15	5,17	6,22		5,16	5,67	5,15	5,26	5,54	5,32	7,02	11,36	
	5,61	13,38	5,18	6,24		5,16	5,58		5,16		5,23	7,04		
	5,56		5,31	6,21		5,22	5,50		5,16		5,23			
	5,51		5,30	6,20		5,20	5,47		5,16		5,36			
	5,44		5,31	6,18		5,18	5,45		5,28		5,92			
	5,41		5,38	6,20			5,38		5,30		5,99			
	5,36		5,58	6,28			5,34		5,33		5,92			
	5,32		5,55	6,35			5,32		5,33		5,86			
	5,27		5,50	6,45			5,30		5,36		5,80			
	5,24		5,41	6,92			5,24		5,23					
			5,36	6,95			5,19							
			5,42											
			5,45											
			5,52											
			5,54											mm
			5,60											

C1	C2	C3	C4	C5	C6	C8	C9	C10	C11	C12	C13	C14	C15	C16
5.21	4.94	5.78	5.61	5.55	4.89	5.60	5.44	5.30	4.96	5.15	4.96	5.36	5.26	4.89
5,29	4,98	5,79	5,65	5,74	4,92	5,73	5,68	5,27	5,04	5,15	5,08	5,28	5,20	4,95
5,31	4,96	5,87	5,67	5,59	4,97	5,84	5,86	5,15	5,11	5,06	5,16	5,28	5,22	5,03
5,32	5,02	5,87	5,75	5,46	5,03	5,75	6,30	5,15	5,27	4,94	5,33	5,36	5,21	5,10
5,36	5,07	5,90	5,76	5,31	5,09	5,72	5,84	5,15	5,36	4,96	5,36	5,51	5,10	5,29
5,46	5,22	5,91	5,83	5,22	5,17	5,67	5,76	5,18	5,26	5,10	5,26	5,56	4,96	5,28
5,50	5,23	5,90	5,85	5,25	5,38	5,55	5,66	5,20	5,18	5,67	5,20	5,58	4,90	5,19
5,55	5,20	5,82	5,83	5,38	5,42	5,48	5,55	5,15	5,18	5,81	5,25	5,43	5,02	5,16
5,63	5,13	5,78	5,86	5,79	5,38	5,32	5,43	5,11	5,28	5,83	5,30	5,27	5,60	5,17
5,70	5,15	5,75	5,89	5,98	5,29	5,23	5,36	5,10	5,33	5,83	5,42	5,19	5,72	5,16
5,73	5,21	5,70		6,17	5,33	5,16	5,47	5,07	5,37	5,77	5,44	5,22	5,86	5,30
5,76	5,32	5,67		6,25	5,38	5,17	5,68	5,00	5,40	5,71	5,42	5,34	5,86	5,34
5,81	5,32	5,61		6,31	5,52	5,23	6,01	4,98	5,44	5,57	5,38	5,91	5,86	5,33
5,84	5,34	5,57		6,36	5,51	5,46		5,03	5,46	5,47	5,39	5,98	5,72	5,31
5,78	5,46	5,53		6,44	5,54	5,58		5,10	5,39	5,37	5,28	6,11	5,70	
5,77	5,39	5,47			5,56	5,49		5,15	5,24	5,30	5,21	6,17		
	5,31	5,35			5,54	5,41		5,23	5,21	5,26	5,18	6,28		
		5,28			5,49	5,20		5,42	5,20	5,31	5,20	6,28		
		5,19			5,39	5,18		5,46	5,23	5,48	5,19	6,29		
		5,18				5,21			5,23	5,60	5,14	6,35		
		5,22				5,40			5,20					
		5,24				5,84			5,25					
						6,01			5,35					
						6,15			5,31					
						6,22			5,21					mm

Πίνακας 3 Οι διατομές πάχους των 34 οστράκων από το αντίγραφο του κεραμικού αγγείου.

Επιπλέον παράγεται και μια συγκεντρωτική σελίδα (Εικόνα 7/δεξιά) με όλες τις πληροφορίες για όλα τα όστρακα του αγγείου. Το λογισμικό διαθέτει επιπλέον δυνατότητες αυτόματου προσανατολισμού των οστράκων «σε σχέση με το έδαφος» και συνεπώς δεν χρειάζεται τα όστρακα κατά τη διαδικασία της ευθυγράμμισης τους με τα laser, να προσανατολίζονται και σε σχέση με το έδαφος (για το εάν δηλαδή τα κρατάμε ανάποδα ή όχι). Απλά στην χειρότερη περίπτωση, το λογισμικό θα καθοδηγήσει τον αρχαιολόγο/χρήστη να πάρει ολόκληρο το αγγείο ανάποδα. Οι σημαντικότερες πληροφορίες από τις τρεις σελίδες του λογισμικού αποτυπώνονται μέσα σε δύο γραμμές, όπως αυτές επεξηγούνται αναλυτικά στην Εικόνα 8, για το αποτέλεσμα του ταιριάσματος του ζεύγους των οστράκων B2 και A5, όπως αυτό εμφανίζεται στον Πίνακα 2 (το πρώτο ζευγάρι επάνω αριστερά).

2.γ Το πείραμα «*οι Νάνοι και ο Γίγαντας*»

Σε κάθε περίπτωση ανακατασκευής ενός σπασμένου κεραμικού αγγείου το προς ανασύσταση διαθέσιμο υλικό συμπεριλαμβάνει και ένα ποσοστό από πολύ μικρά θραύσματα, τα οποία δεν παρέχουν αρκετές πληροφορίες και δυσκολεύουν το έργο των αρχαιολόγων.

Στην περίπτωση του κεραμικού αντιγράφου, το υλικό αυτό έφτανε το 12% (15 μικρά θραύσματα). Για την επίδειξη της μεθόδου στην σύνθετη αυτή περίπτωση, διερευνήθηκε το σύνολο των μικρών οστράκων («*Νάνοι*») σε σχέση με τις δυνατότητες ταιριάσματος προς το μεγαλύτερο διαθέσιμο όστρακο («*Γίγαντας*»). Με το ειδικό λογισμικό της μεθόδου και βάση των σχετικών υποδείξεων (Πίνακας 1) τα 15 μικρά όστρακα τοποθετήθηκαν (ή απορρίφθηκαν) με απόλυτη επιτυχία στο μεγαλύτερο διαθέσιμο όστρακο Α1. Θα πρέπει να σημειωθεί ότι ακόμη και για μικρά όστρακα που δεν εφάπτονταν με το όστρακο οδηγό Α1, η μέθοδος τα τοποθετεί με επιτυχία στο κατάλληλο ύψος με βάση την τοπική διατομή πάχους του αγγείου. Για την τελική οπτική παρουσίαση των αποτελεσμάτων του πειράματος «*οι Νάνοι και ο Γίγαντας*», τα 16 όστρακα (15+1) τοποθετήθηκαν επάνω σε ένα μεταλλικό πλέγμα, αντίγραφο του κεραμικού αγγείου (Εικόνα 9).

Εικόνα 11 Δυο ολοκληρωμένες *Λοπάδες*, [www.britishmuseum.org, Collection id=3309459].

Εικόνα 12 Τα 9 όστρακα της *Λοπάδας* (400 π.Χ.).

2.δ Αποτελεσματικότητα 95%

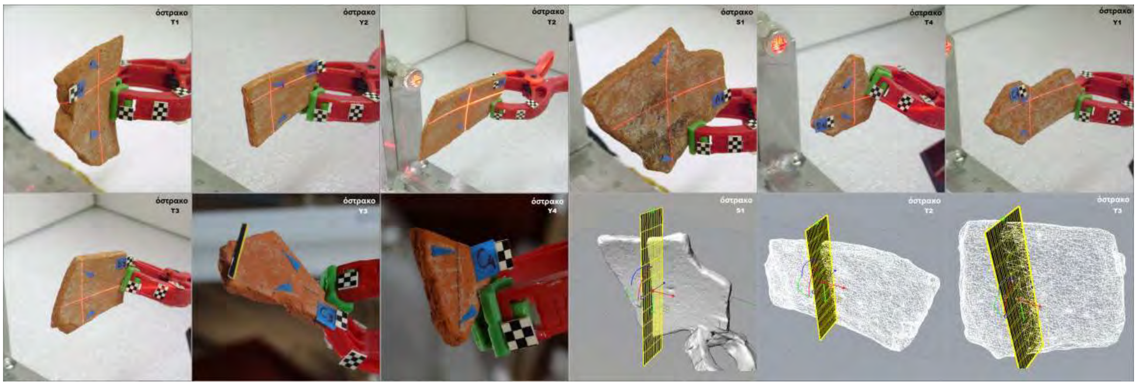
Το αντίγραφο του σύγχρονου κεραμικού αγγείου ανακατασκευάστηκε ψηφιακά με τη μέθοδο *Διατομής Πάχους* με αποτελεσματικότητα που καλύπτει το 95% του διαθέσιμου προς επεξεργασία υλικού (πέντε όστρακα στην Εικόνα 4/θ, δεκαπέντε στην Εικόνα 9 και δώδεκα όστρακα στην Εικόνα 10). Στην Εικόνα 10, παρουσιάζεται η επιτυχής συνένωση όλων των οστράκων από τα πλευρικά τοιχώματα του αγγείου, με βάση τις επιτυχημένες υποδείξεις του λογισμικού (Πίνακας 2). Στον Πίνακα 3, παρουσιάζονται όλες οι διατομές πάχους όπως αυτές εξήχθησαν από τα 34 ψηφιακά μοντέλα των οστράκων του πειράματος.

3. Ένα αυθεντικό αγγείο από το 400 π.Χ.

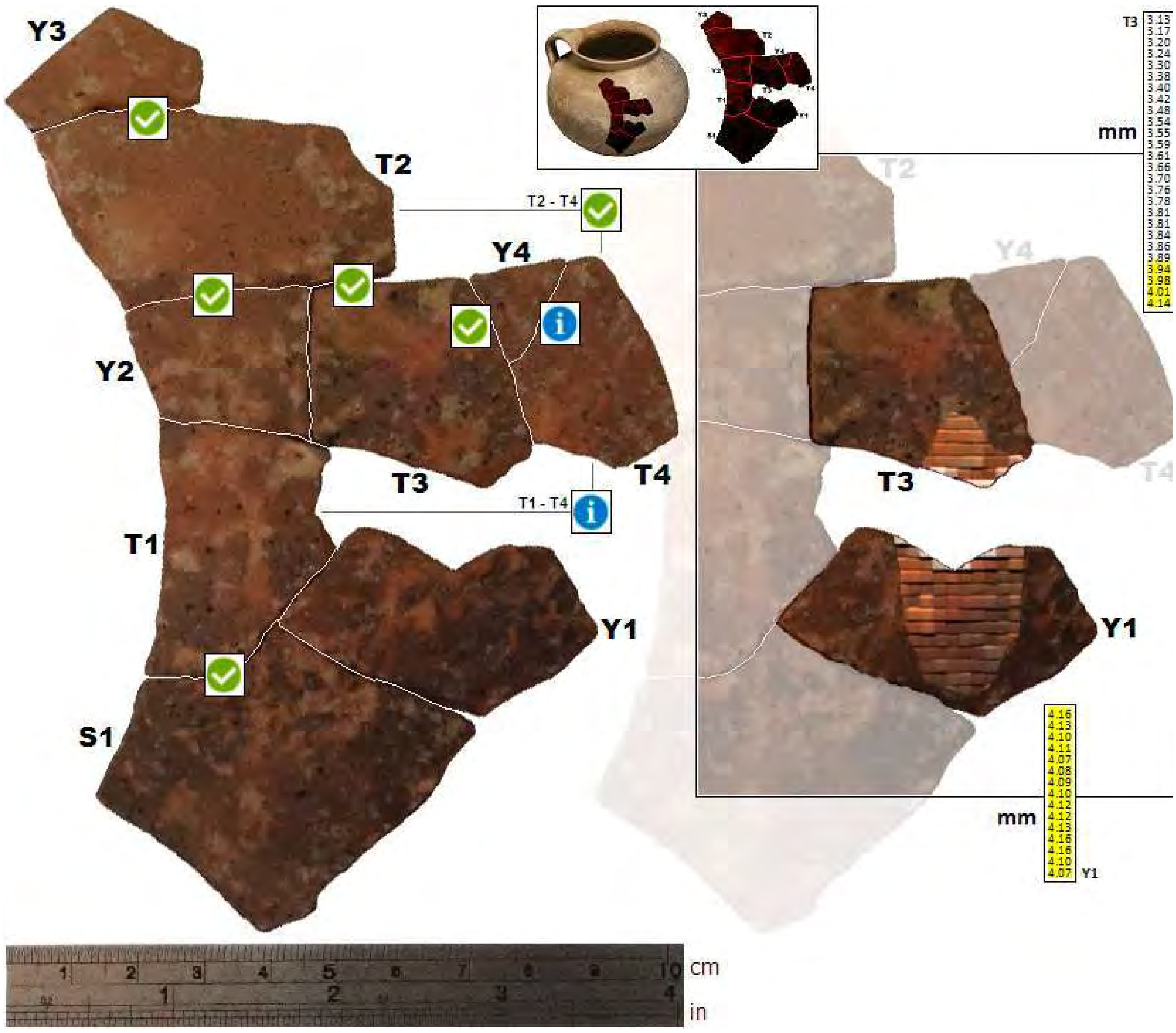
Σε αυτή την ενότητα διερευνούμε ένα αυθεντικό υποσύνολο από συνανήκοντα όστρακα άβαφης κεραμικής του 400 π.Χ. πιθανότατα από μια *Λοπάδα* (μαγειρικό σκεύος, χύτρα), το οποίο βρέθηκε σε ανασκαφή στο Καβούρι στην Βουλιαγμένη Αττικής (Εικόνες 11 και 12). Ορισμένα από τα όστρακα παρουσιάζουν εκτεταμένες φθορές. Στην Εικόνα 13, παρουσιάζονται διάφορες όψεις των οστράκων κατά τη διαδικασία της ευθυγράμμισης για την εξαγωγή των καθέτων τομών. Ο Πίνακας 4, παρουσιάζει τις διατομές πάχους των οστράκων της *Λοπάδας*.

S1	T1	T2	T3	T4	Y1	Y2	Y3	Y4
3,52	3,57	2,82	3,13	2,98	4,16	3,40	2,70	3,23
3,57	3,62	2,88	3,17	3,08	4,13	3,45	2,68	3,27
3,58	3,64	2,93	3,20	3,13	4,10	3,50	2,73	3,20
3,52	3,63	2,94	3,24	3,17	4,11	3,41	2,76	3,22
3,54	3,64	2,96	3,30	3,21	4,07	3,42	2,77	3,28
3,51	3,67	2,99	3,38	3,27	4,08	3,40	2,75	3,28
3,47	3,68	3,02	3,40	3,31	4,09	3,37	2,75	3,30
3,45	3,69	3,08	3,42	3,36	4,10	3,38	2,75	3,34
3,45	3,66	3,04	3,48	3,40	4,12	3,37	2,75	3,38
3,38	3,68	3,07	3,54	3,43	4,12	3,38	2,78	3,40
3,43	3,67	3,13	3,55	3,48	4,13	3,37	2,78	3,39
3,43	3,63	3,13	3,59	3,47	4,16	3,38	2,77	3,45
3,44	3,61	3,15	3,61	3,43	4,16	3,37	2,78	
3,38	3,62	3,16	3,66	3,41	4,10	3,36	2,78	
3,37	3,61	3,17	3,70	3,39	4,07	3,34	2,76	
3,36	3,56	3,16	3,76	3,45		3,34		
3,40	3,54	3,20	3,78	3,47		3,38		
3,41	3,50	3,21	3,81	3,46		3,39		
3,40	3,47	3,23	3,81	3,49		3,41		
3,40	3,46	3,28	3,84	3,44				
3,40	3,44	3,30	3,86	3,48				
3,41	3,43	3,31	3,89	3,49				
3,44	3,44	3,31	3,94	3,52				
3,43	3,42	3,36	3,98	3,55				
3,46	3,44	3,38	4,01	3,57				
3,52	3,45		4,14					
3,47	3,43							
3,48	3,46							
3,50	3,48							
3,49	3,50							
3,50	3,50							
3,47	3,50							
3,44	3,54							
3,45	3,56							
3,42	3,54							
3,43	3,55							
3,42	3,54							
3,40								
3,38								mm

Πίνακας 4 Οι διατομές πάχους της *Λοπάδας*. Με κίτρινη επισήμανση το τοπικό «φούσκωμα», ίσως από τη θέση μιας λαβής ή μιας οπής στο αγγείο.



Εικόνα 13 Τα 9 όστρακα της *Λοπάδας* κατά τη διαδικασία της ευθυγράμμισης.



Εικόνα 14 Το τελικό οπτικό αποτέλεσμα από την ανακατασκευή της *Λοπάδας*.

ζευγάρι	σκορ & προτεινόμενη θέση	σχόλιο	
(**Y3**) vs (**T2**) 15/ 25, 5	εντός 38,00 /15 CH +1mm (M) εκτός 5,00/ 5 CH -10mm (oM)	ΑΠΟΡΡΙΨΗ ΤΑΙΡΙΑΣΜΑ !	✓
(**T1**) vs (**S1**) 37/ 39, 15	εντός 37,00/37 CH +1mm (R) εκτός 14,00/26 CH -11mm (oM)	ΑΠΟΡΡΙΨΗ ΤΑΙΡΙΑΣΜΑ !	✓
(**T4**) vs (**T1**) 25/ 37, 5	εντός 33,00/25 CH +12mm (R) εκτός 3,00/ 5 CH -20mm (oM)	ΑΠΟΡΡΙΨΗ ΠΟΛΥ ΠΙΘΑΝΟ	i
(**T4**) vs (**T2**) 25/ 25, 5	εντός 64,00/25 CH +1mm (M) εκτός 6,00/24 CH -16mm (Mu)	ΑΠΟΡΡΙΨΗ ΤΑΙΡΙΑΣΜΑ !	✓

ζευγάρι	σκορ & προτεινόμενη θέση	σχόλιο	
(**Y4**) vs (**T4**) 12/ 25, 5	εντός 8,00 /12 CH +1mm (M) εκτός 7,00 /11 CH -1mm (oM)	ΑΠΟΡΡΙΨΗ ΠΟΛΥ ΠΙΘΑΝΟ	i
(**Y4**) vs (**T3**) 12/ 26, 5	εντός 10,00 /12 CH +1mm (M) εκτός 4,00/ 9 CH -3mm (oM)	ΑΠΟΡΡΙΨΗ ΤΑΙΡΙΑΣΜΑ !	✓
(**T3**) vs (**T2**) 26/ 25, 5	εντός 0,00/26 CH +0mm ( ) εκτός 4,00/25 CH -18mm (Mu)	- ΤΑΙΡΙΑΣΜΑ !	✓
(**Y2**) vs (**T2**) 19/ 25, 5	εντός 38,00/ 19 CH +7mm (M) εκτός 5,00/ 18 CH -21mm (Mu)	ΑΠΟΡΡΙΨΗ ΤΑΙΡΙΑΣΜΑ !	✓

Πίνακας 5 Τα συγκεντρωτικά αποτελέσματα του λογισμικού με τις προτάσεις των ταιριασμάτων.

Στην Εικόνα 14, παρουσιάζεται το τελικό οπτικό αποτέλεσμα με τα ανασυναρμολογημένα όστρακα. Τα όστρακα με κωδικό T3 και Y1 εμφανίζουν ένα τοπικό «φούσκωμα» όπως αυτό αποτυπώνεται στην Εικόνα 14/δεξιά και ως εκ τούτου δεν μπορούν εύκολα να συνδυαστούν με τα υπόλοιπα. Ακόμη και σε αυτή την δύσκολη περίπτωση, με τα μικρά και μερικώς κατεστραμμένα όστρακα, η μέθοδος επιτυγχάνει πολύ ικανοποιητικά αποτελέσματα, όπως φαίνεται στον Πίνακα 5 με τις προτάσεις του λογισμικού. Δεδομένου ότι η μέθοδος *Διατομής Πάχους* είναι αποτελεσματική, ακόμη και όταν κάποιο ή κάποια από τα κομμάτια του αγγείου εξακολουθούν να αγνοούνται ή να έχουν υποστεί ζημιά στις επιφάνειες του σπασίματος (δηλαδή να έχουν μεγάλο κατώφλι φθοράς) το συγκεκριμένο παράδειγμα είναι ιδανικό για την ανάδειξη των πλεονεκτημάτων της νέας μεθόδου. Οποιαδήποτε άλλη μέθοδος (που θα βασιζόταν στο ταίριασμα των σπασμένων επιφανειών), θα ήταν καταδικασμένη σε αποτυχία και αυτό μπορεί να έχει ιδιαίτερη σημασία για τους αρχαιολόγους.

Συμπεράσματα

Χρησιμοποιώντας τεχνολογίες αιχμής, όπως η φωτογραμμετρία, η τρισδιάστατη μοντελοποίηση, η εξαγωγή και η επεξεργασία τρισδιάστατων (3Δ) ψηφιακών μοντέλων, παρουσιάσαμε μια νέα επιστημονική μέθοδο, η οποία χρησιμοποιώντας μετρήσεις πάχους σε όστρακα, μπορεί με βεβαιότητα να βοηθήσει τα εργαστήρια συντήρησης κεραμικών στην ανακατασκευή θραυσμένων αρχαίων αγγείων. Πιστεύουμε ότι έχουμε εισαγάγει μια νέα μέθοδο επίλυσης του δύσκολου προβλήματος της ψηφιακής ανακατασκευής ενός σπασμένου κεραμικού αγγείου.

Αξίζει να σημειωθεί, ότι κατά την πειραματική αξιολόγηση, η μέθοδος *Διατομής Πάχους*, εφαρμόστηκε σε μεγάλο αριθμό από πολύ μικρά κεραμικά θραύσματα άβαφης κεραμικής (σε αυθεντικά και συνθετικά κεραμικά θέματα), προσδίδοντας ιδιαίτερη σημασία στα αποτελέσματα. Σκοπεύουμε να τελειοποιήσουμε τη μέθοδο μας, εφαρμόζοντας την επάνω σε σύνθετα κεραμικά αγγεία από κάποια συλλογή μουσείου σε χώρες υψηλού αρχαιολογικού ενδιαφέροντος (ειδικά σε θέματα από την αρχαϊκή, κλασική ή ελληνιστική εποχή).

Ευχαριστίες

Οι συγγραφείς θα ήθελαν να εκφράσουν τις ευχαριστίες τους, στην κυρία Μαίρη Γιαμαλίδη και στην κυρία Κατερίνα Παναγοπούλου, από την Εφορεία Αρχαιοτήτων Δυτικής Αττικής, Πειραιώς και Νήσων, για την αρχαιολογική τους υποστήριξη. Επίσης ευχαριστούμε όλους τους αρχαιολόγους από το αρχαιολογικό Μουσείο του Πειραιά και από την αρχαιολογική υπηρεσία στο Ελληνικό.

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IN AND OUT: CFD MODELLING OF THE TEMPERATURE DISTRIBUTION INSIDE AN ANCIENT UPDRAFT POTTERY KILN

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Περίληψη/Abstract

Στην παρούσα εργασία παρουσιάζεται μία προσέγγιση μοντελοποίησης της δομής και της λειτουργίας κεραμικών κλιβάνων αρχαιολογικού ενδιαφέροντος. Για το σκοπό αυτό αναπτύχτηκαν τρισδιάστατα μοντέλα κλιβάνων με βάση αρχαιολογικά δεδομένα και η κατανομή θερμοκρασιών στο εωτερικό τους υπολογίστηκε με χρήση υπολογιστικής ρευστομηχανικής (computational fluid dynamics - CFD). Με βάση τα δεδομένα για τους κλιβάνους που μελετήθηκαν, το εσωτερικό τους διαιρέθηκε σε δύο ζώνες: το χώρο καύσης και το χώρο όπτησης των κεραμικών. Οι δύο ζώνες διαιρέθηκαν σε κυψελίδες, όπου το πάτωμα και τα τοιχώματα ορίζουν την περιοχή μεταφοράς της θερμότητας. Ο αέρας εισέρχεται από το χώρο καύσης από το σχετικό άνοιγμα και η θερμότητα παράγεται από την κάυσιμη ύλη (ξύλα) που θεωρούμε ότι καταλαμβάνουν μέρος του χώρου καύσης. Η καμινάδα στην κορυφή του θαλάμου όπτησης λειτουργεί σαν έξοδος διαφοράς πίεσης. Οι υπολογισμοί, χρησιμοποιώντας τη λύση της σταθεράς κατάστασης, δίνουν στοιχεία για τις απαιτήσεις σε ενέργεια, την κατανομή θερμοκρασιών και καταδεικνύουν τη σημασία της χωροθέτησης των κεραμικών αγγείων στο θάλαμο όπτησης.

In the present paper, a modelling approach for assessing ancient kiln designs is introduced and demonstrated. 3D models of updraft kilns are created based on archaeological examples and the temperature distribution inside the kiln is evaluated by fluent modelling using computational fluid dynamics (CFD). Following the actual kiln design the interior is divided in two cell zones, stoking chamber and ware chamber. The two zones are meshed and floor and walls are defined as boundary conditions for fluid/solid heat transfer. Air enters the stoking chamber through a velocity inlet and heat energy is generated with the wood partially filling up the space. A chimney at the top of the ware chamber is serving as pressure outlet. Calculations using a steady-state solution provide information about energy requirements as well as the temperature distribution within the kiln, indicating the crucial impact of the arrangement of the pottery inside the ware chamber.

Keywords: Pottery kilns, Temperature, CFD modelling, Finite volumes

Introduction

A decisive step in ceramic production is the firing of an object, which has been molded from clay, transforming it eventually into a ceramic object. During the firing process heat is transferred to the object, altering its mineralogical composition and the material's microstructure and texture, and thus changing non-reversibly the object's material properties. In this process, the kiln serves as functional device complying with certain operational principles (Kingery 1997). Specific functions of a pottery kiln are heat generation, commonly by combustion, heat transfer to the ware, heat containment and stable setting of the ware. Therefore, it is worthwhile to investigate ancient ceramic kilns and their design in view of these functional constraints and their performance characteristics, such as achievable temperature and heating efficiency (Prillwitz & Hein 2015).

Before the use of built kiln structures ceramics were fired in open firing systems. In the simplest case the clay objects were placed inside a pile of fuel. Even though in this way already temperatures up to 900 °C could be reached, the temperatures were difficult to be controlled and maintained (Gosselain & Livingstone-Smith 1995). A more advanced firing method was pit firing, an open firing with the ware placed along with the fuel or covered with it inside a pit, a set-up which provided some basic heat containment. Only with the construction and use of kiln structures, however, firing conditions could be sufficiently controlled and temperatures could be reached and sustained, allowing for the production of high quality earthenware with an adequately vitrified ceramic fabric and advanced surface decorations. The first double-chamber kilns were presumably developed in the Near East more than 8000 years ago (Rice 1987, 158). In the Eastern Mediterranean region updraft or cross-draft kilns appear to have been the common kiln types since the Middle Bronze Age (Hansen-Streily 2000, 80). The fuel was placed and charged from the side in a stoking chamber or fire box, which was connected to the so-called combustion chamber.

The ceramics were placed separately on an elevated level in the connected ware chamber, using for example platforms constructed from mudbricks or perforated ceramic floors. Heat and flue gases escaped from the top of the ware chamber either through a chimney in permanent roof structures or an opening in a temporary covering.

The heat in a ceramic kiln was generated in general by combustion of biomass fuel, such as wood, straw or chaff. The heat value of wood is typically in the range of 15-20 MJ/kg. However, the achievable temperatures are not only a matter of the total heat value of the fuel but rather of the rate of combustion. The latter depends on the available space for the fuel in the stoking chamber, on the air supply, on the flow resistance of the fuel bed and on the fuel replenishment (Rehder 2000). Therefore, the design of the stoking chamber has a direct impact on the combustion temperature of the fuel. The operation temperature of a kiln is affected furthermore by the heat loss through the kiln structure, which depends on design parameters, such as wall thickness and geometry, but also on the material properties of the building materials (Prillwitz & Hein 2015).

Apart from these basic design principles considerable variation in kiln architecture is observed in the archaeological record; a fact which has been related to regional traditions or chronological developments (Hasaki 2002). Of crucial importance, however, is also the proper operation of a kiln and functional aspects might have played a role in certain design decisions. We present a novel approach to investigate such issues based on three-dimensional kiln models. These allow for the functional study of different kiln design decisions by investigating the temperature development and temperature distribution during simulated kiln operation using fluent modelling. In the present paper, the modelling approach will be introduced and demonstrated for a kiln design model based on the archaeological example of a Late Helladic (LH) two chamber updraft pottery kiln.

1. Computational Fluid Dynamics (CFD)

In order to estimate the temperature distribution inside a kiln the air flow and the related heat transfer has to be examined. Heat and mass transport of a fluid or gas, such as in the present case the air flow inside the kiln, can be investigated with computational fluid dynamics (CFD) (Tabor *et al.* 2005). The interior of the kiln is subdivided in small sub-regions or finite volumes connected among each other via nodes, quite similar to the approach used in structural analysis using the finite element method (Hein & Kilikoglou 2015). The fluent zones inside the kiln are defined by a 3-dimensional model of the built kiln structure. The heat transfer between air and kiln structure can be considered either by integrating the different parts of the kiln structure as solid zones into the model or by defining their surfaces as boundary walls.

The simulated air flow through the kiln is essentially defined by an inlet with predetermined air velocity and temperature, and an outlet considering ambient pressure and gravity. Inside the modeled stoking chamber heat exchange between the burning fuel and the flowing air is simulated. For this the fuel bed can be defined as porous zone either with a predefined constant temperature or as energy source with a presumed heating rate. The draft is enhanced by the buoyancy of the heated air. Once the model and the boundary conditions are appropriately set up the system is ready to be solved. In order to assess the operating conditions of the fully heated kiln a steady-state solution is adequate. In the case that the heating up of the kiln is considered as well a transient solution will need to be chosen, which will require, however, considerably more computing time.

2. Kiln model

2.a Archaeological Evidence

The CFD approach was tested with a model designed on the basis of a LH kiln excavated in Rhodes (Marketou 2004). The kiln walls had been constructed with mud bricks and the combustion and ware chamber had a circular layout with an internal diameter of c. 2 m (Fig. 1). The ware was apparently placed on three wall-like platforms, which divided the air flow effectively in four fire channels. The platforms had been constructed with mud bricks as well. The upper part of the ware chamber was not preserved, so that there was no evidence for the original height of the kiln.

The combustion chamber was heated laterally through a stoking chamber of c. 2 m length, in relation to which it was elevated. The mineralogical examination of samples taken from the kiln lining at different spots inside the kiln provided an estimation of the maximum temperatures emerging in the kiln during firing and their spatial distribution (Müller *et al.* forthcoming). The estimated firing temperatures provided a genuine framework for comparison with simulated temperature distributions of the kiln model, in order to refine the model and to investigate the operating parameters of the kiln.

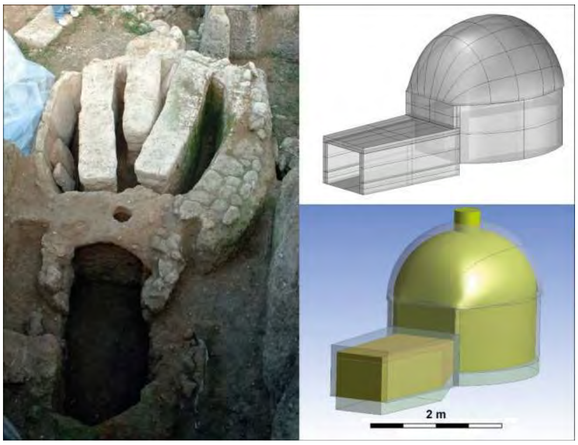

Figure 1 Three-dimensional kiln model based on a LH kiln excavated in Rhodes (left): The dome was freely reconstructed using arcs. The interior of the kiln chambers was filled with fluent bodies and a chimney was added.

2.b CFD model

Based on the actual dimensions of the excavated kiln a simplified 3-dimensional digital model of the kiln structure was generated (Fig. 1). The non-preserved upper part of the ware chamber was re-constructed as a dome assuming arcs starting from the base walls of the ware chamber. Furthermore, the stoking chamber was assumed to have been covered with mud bricks. The geometry of the solid kiln structure was used to define the internal volumes of stoking, combustion and ware chamber as fluid bodies. Finally, a cylinder was added at the top of the ware chamber, simulating a chimney (Fig. 1). Position and internal diameter of the chimney can be investigated as additional parameters. In the present model, the chimney was centrically placed and its inner diameter of 40 cm corresponded to c. 20 % of the diameter of the combustion and ware chamber. Eventually, the modeled stoking chamber had a volume of c. 1.2 m^3 while the modeled combustion and ware chamber had a volume of c. 4.9 m^3.

In order to simulate heat transfer from the burning fuel to the passing air flow the lower part of the stoking chamber was set up as fuel bed. For this it was defined as porous body with the respective flow resistance and either pre-defined flame temperature or an energy source corresponding to the assumed heating rate of the fuel. The stoking hole was set up as inlet with pre-defined air velocity and ambient temperature of 300 K. Various velocities were tested in order to investigate the impact of the natural wind speed on the operating conditions of the kiln. Accordingly, the top area of the chimney was defined as outlet, considering the buoyancy of the heated air with the assumed gravity field and the ambient air pressure as boundary condition.

In the case of the pottery wares assumedly placed in the ware chamber their flow resistance could not be adequately considered as porous body. Instead, a solid ceramic body was defined inside the ware chamber. For this several layers of hollow half spheres were placed above the platforms, simulating open ceramic bowls piled up for firing (Fig. 2).

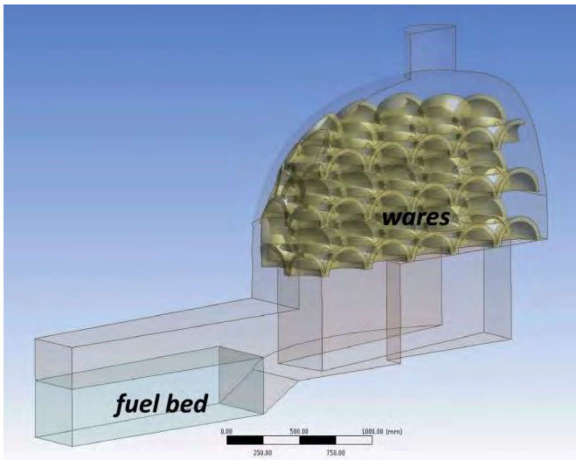

Figure 2 Three zones are evaluated in the CFD simulation: Apart from the air flow in the interior of the kiln the lower part of the stoking chamber is defined as porous fuel bed and a solid body simulating the pottery is placed in the ware chamber.

In order to reduce the number of volume elements and thus the calculations the kiln model was divided in half along its longitudinal direction and the section was defined as symmetry plane. The fluid bodies and the solid ceramic body were meshed with an initial element size of 5 cm, resulting in c. 2,800,000 elements connected through c. 620,000 nodes (Fig. 3). The body parts of the solid kiln structure were not included in the meshing but their internal surfaces were defined as boundary walls, with pre-defined wall thickness, boundary conditions of the external wall surface and the respective material properties for heat transfer. For the CFD solver a steady pressure-based solution was selected considering energy balance and turbulent flow. The solution was expected to provide an estimation of the temperature distribution in the kiln once steady state and equilibrium was reached.

3. Results and Discussion

3.a Temperature distribution inside the kiln

Figure 4 shows the temperature distribution assuming a flame temperature of the burning fuel of 1800 K, which is slightly lower than the maximum temperature of c. 1600 °C that can supposedly be reached by combustion of biomass fuel (Rehder 2000). The two models depicted in Figure 4 show the simulated temperature distribution in the three calculated zones for different heights of the fuel bed.

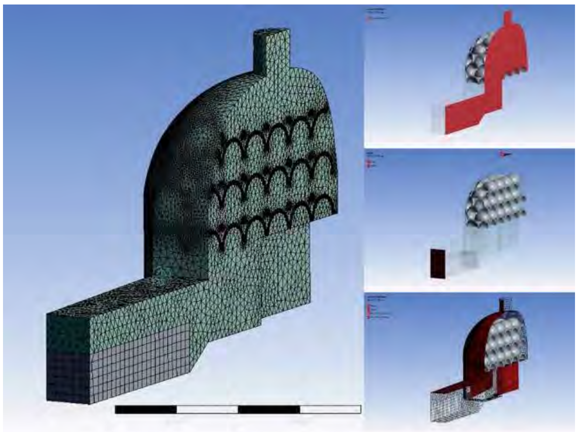

Figure 3 Meshed zones and boundary conditions: The kiln model is cut in half along the longitudinal direction and the section is defined as symmetry plane. The stoking hole is set up as velocity inlet and the chimney as outlet. Walls, floor and platforms are set up as boundary walls.

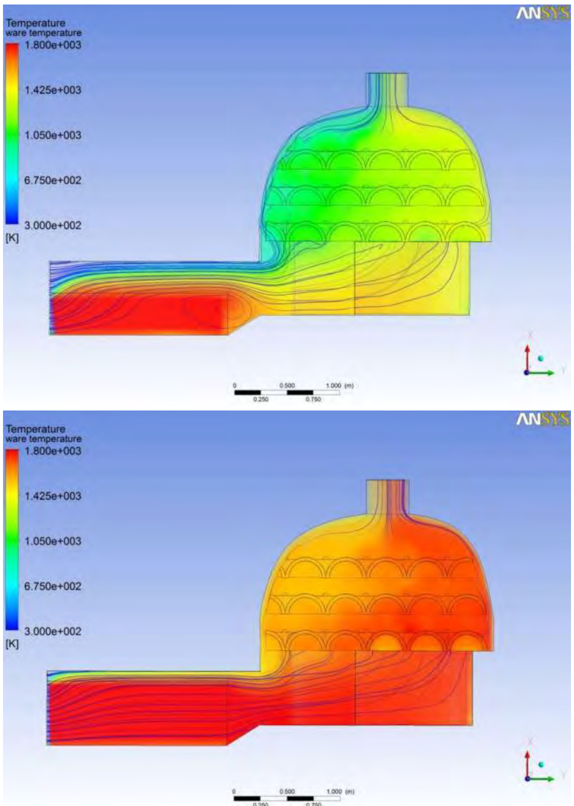

Figure 4 Temperature distribution inside the kiln assuming a flame temperature of the burning fuel of 1800 K: In the upper model the fuel bed was set up with a height of 40 cm and in the lower model with a height of 60 cm, which cover c. 57 % or c. 86 % of the internal height of the stoking chamber, respectively. The blue curves indicate the flow of air and the flue gas inside the kiln.

This obviously affects the temperature distribution inside the ware chamber not only in terms of the maximum temperature reached but also in terms of the adequate uniformity of the temperature distribution in the ware chamber, an important prerequisite for successful kiln firing. The model with the lower fuel bed exhibits larger temperature differences between the front part and the back part of the ware chamber, most probably due to the different flow of the flue gas.

3.b Flow of air and flue gas

The flow of air and flue gas can be further investigated by evaluating the simulated velocities (Fig. 5). For the present model, a porosity of 60 % is assumed for the fuel bed and an initial air velocity of 3 m/s at the stoking hole, corresponding to a light to gentle breeze. Inside the kiln the hot flue gas is accelerated due to buoyancy with velocities clearly above 10 m/s above the fuel bed and inside the chimney. Even higher velocities are indicated in particular spaces between the ceramics in the ware chamber. The trajectories of the flue gas flow illustrate the considerable impact of the pottery wares, which essentially deflect the flue gas. In the present model, a simple arrangement of rather basic vessel shapes was selected. It can be expected, however, that alternative stacking arrangements or vessel shapes will profoundly affect the flue gas flow as well as the temperature distribution inside the ware chamber.

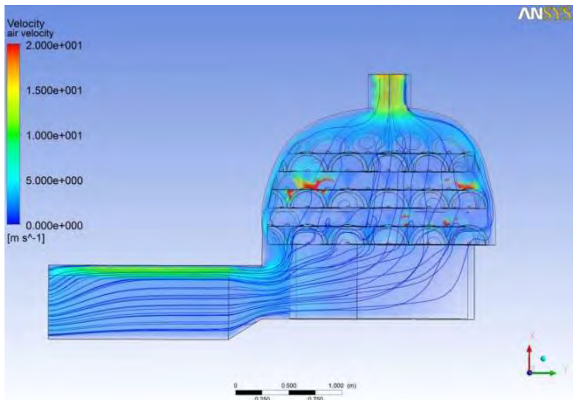

Figure 5 Velocity distribution and flow of air and flue gas inside the kiln: At the stoking hole wind speed of 3 m/s was assumed. Particularly high velocities are indicated above the fuel bed, inside the chimney and in some spaces between the wares.

3.c Temperature and heat flux at the boundary walls

Apart from the temperature distribution of the air and flue gas inside the kiln and the temperature of the pottery wares also the temperature profiles of the internal surfaces of the kiln structure can be assessed (Fig. 6). In the present model, a mud brick wall with a thickness of 30 cm is assumed while the mud brick platforms and the kiln floor, assumedly out of dolomitic rock, are set up with practically infinite thickness. The simulated internal wall temperature is particularly interesting in view of their comparison with the temperature estimations of actual ancient kiln linings by material analyses. It is such analytical work on archaeological kiln structures which initiated the impetus for the present simulation (Prillwitz & Hein 2015).

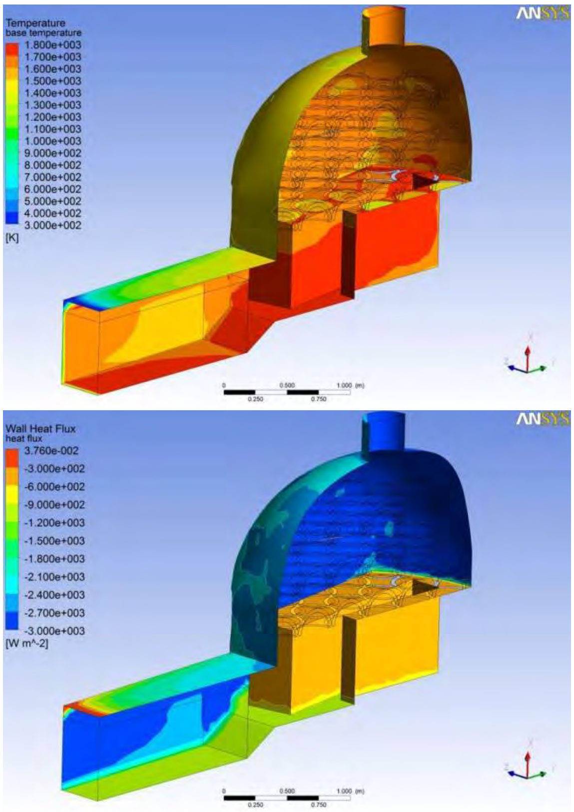

Figure 6 Temperature profile and heat flux of the internal surfaces of the kiln construction, which are not part of the model but set up as boundary walls.

In the present case study, the simulated temperatures are compared with temperature estimations, based on investigation of the kiln lining, which was sampled in different zones of the original kiln (Müller *et al.* forthcoming). In this way, the model can be refined and adjusted. Additional information can be achieved for example about the construction of the upper part of the ware chamber or the position of the chimney. Interestingly, the results of the present simulation indicate areas with lower surface temperatures on the platforms. These are related to pottery wares placed from above suppressing the flue gas flow.

Apart from the surface temperature the heat flux though the boundary walls can be evaluated in view of heat loss and the related heating efficiency of the kiln (Fig. 6). Thickness and thermal properties of the mud brick wall can be varied in order to investigate the impact of these parameters on the simulated heat loss and heating efficiency. A complete assessment, however, will require transient solution of the system in order to consider also the heating up of the entire construction during the initial phase of the firing process.

3.d Estimation of the fuel consumption

In order to estimate the amount of fuel necessary to maintain suitable firing temperatures inside the kiln the fuel bed can be set up as energy source instead of defining a specific flame temperature. Figure 7 presents a model with the fuel bed set up as energy source of 750 kW/m^3 corresponding in the case of the modeled fuel bed to a combustion rate of c. 2400 MJ or c. 120 kg wood per hour. This does not consider, however, the heating up of the kiln structure and the firing of the ware, but only the maintenance of maximum temperatures of up to 1300 K in the ware chamber once a steady state is reached.

The simulation results of this model appear to be more susceptible to boundary conditions, such as initial velocity at the inlet or height and flow resistance of the fuel bed. In the case that the fuel bed covers the entire height of the stoking chamber, for example, c. 20 % less fuel would be necessary to maintain the same temperatures.

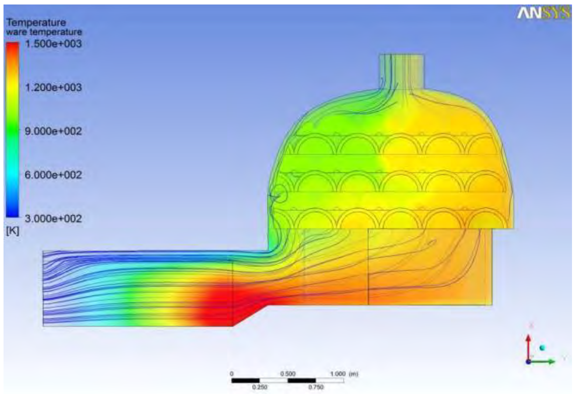

Figure 7 Temperature distribution inside the kiln assuming an energy source of 750 kW/m^3 in the fuel bed.

Conclusions

The present case study has demonstrated the potential of CFD modelling for assessing specific kiln designs, in terms of achievable temperatures and heating efficiency. Apart from kiln geometry and air velocity at the inlet, the air flow and temperature distribution inside a kiln are affected also by parameters such as height and flow resistance of the fuel bed and by the arrangement of the pottery wares to be fired. Through the boundary conditions the impact of the material properties of the kiln building materials on the heating efficiency can be investigated as well, even without integrating the structures in the model.

For the present model, a steady state solution was selected providing information about the operating conditions of the kiln once equilibrium conditions are reached. In order to investigate the heating up of the kiln structure and the firing of the pottery wares, a transient solution will be necessary. In this case, for example, also potential changes in terms of fuel replenishment and heat generation can be considered. Nevertheless, the presented steady state solution has already provided valuable information, which can be used to compare and evaluate different kiln designs and to assess the development of kiln technology in antiquity in terms of their supposed function and operation. Since the arrangement of the pottery wares proved to have a major impact on the temperature distribution inside the kiln, and as in the present model a rather basic arrangement was selected, alternative arrangements inside the ware chamber and the heat transfer from the flue gas to the pottery are certainly other aspects to be investigated in more detail in future models.

The models and simulations of the kiln operation can be verified and if necessary refined with temperature estimations obtained from the analysis of ancient kiln linings, kiln furniture and ceramics. An alternative approach for testing the models are experimental firings in traditional pottery kilns or in reconstructions of ancient kilns. Apart from the investigation of operating conditions, the assessment of heating efficiency is expected to provide information also concerning topics such as fuel economy, production capacities and environmental impact of pottery production.

Acknowledgements

The original Late Helladic kiln, which was used as prototype for the presented digital model, was excavated at Ialysos in the island of Rhodes. We thank the excavator, Dr. T. Marketou, for providing us with photographs and drawings in order to generate the model.

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THE USE OF COMPUTED TOMOGRAPHY FOR CREATING VIRTUAL ARCHIVES OF CONSERVATION CONDITION REPORTS. THE CASE STUDY OF A 17TH CENTURY CASKET

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Περίληψη/Abstract

Τα δελτία συντήρησης έργων τέχνης είναι ένα πολύ σημαντικό κομμάτι στης διαδικασίας της συντήρησης. Στις μέρες μας, η ψηφιακή τεχνολογία παρέχει νέες μεθόδους, δίνοντας στους ερευνητές την δυνατότητα να χρησιμοποιούν ψηφιακά τρισδιάστατα μοντέλα για την απεικόνιση έργων τέχνης πολιτιστικής κληρονομιάς, σε συνδυασμό με παραδοσιακές μεθόδους. Σκοπός της παρούσας έρευνας είναι να εφαρμόσει τη μέθοδο της Αξονικής Τομογραφίας για τη δημιουργία ψηφιακών δελτίων συντήρηση, αξιολογώντας τα οπτικά αποτελέσματα και το χρόνο που δαπανήθηκε για τη δημιουργία των μοντέλων. Για το σκοπό αυτό έγινε η τρισδιάστατη ψηφιακή καταγραφή δεδομένων ενός κουτιού του 17ου αιώνα από το μουσείο Anne of Cleves House στο Lewes του Ηνωμένου Βασιλείου. Το κουτί θεωρήθηκε κατάλληλο διότι αποτελείται από πέντε διαφορετικά υλικά: ξύλο, αλάβαστρο, ελαιόχρωμα, χαρτί και μεταλλικά στοιχεία. Όπως έδειξε η έρευνα, η τρισδιάστατη Αξονική Τομογραφία παρέχει αποτελέσματα σχετικά με την κατασκευαστική τεχνική του αντικειμένου, τα ακριβή υλικά του και την εξωτερική και εσωτερική κατάσταση διατήρησής του.

Condition reports of artefacts are an important part of the conservation process. Nowadays, digital technology provides more advanced methods, and researchers are using 3D models to illustrate cultural heritage artefacts in a continuation of traditional methods. This paper presents an application of Computed Tomography (CT) and aims to evaluate its use for condition reporting purposes, based on the quality of the resulting visualisations and the time spent for the completion of the model. To accomplish this aim 3D data capturing has been applied on a 17th century casket from Anne of Cleves House Museum in Lewes, UK. The casket was considered appropriate for this study because it consists of five different materials; wood, alabaster, with painted surface, paper and metallic elements. As demonstrated by this research, Computed Tomography provided insights into the construction technique, the exact materials and the internal and external condition of the artefact.

Keywords: Computed Tomography, Digital Condition Reports, 3D Models, Conservation of Artefacts

Introduction

Condition reports are valuable tools in every conservation process. From the early years of conservation science, conservators understood their importance for the successful completion of every conservation project. The reports document the artefact's condition before, during and after the conservation operation and accompany the object in every future process as part of its history. According to the Venice Charter (ICOMOS 1964): *"All works of preservation, restoration or excavation, there should always be precise documentation in the form of analytical and critical reports, illustrated with drawings and photographs"*.

These reports include examination results and analysis of the materials and the construction, and they act as basic tools for any decisions made about future treatment (ICON) (Moore 2001).

Although it is uncertain who first mentioned the procedure, the first references are found c. 1935 as part of seminars and published projects (Moore 2001). The reports usually include written descriptions and visual references. Traditional visual references include photographs (in visible, infra-red and ultraviolet spectrums) and illustrations (such as pencil drawings). Photographs are considered more objective than the more subjective drawings; however, the results of both techniques can give misinterpreted information about an artefact's condition depending on various factors during their creation (lighting, angle, etc.) (Abel *et al*. 2011). Finally, for the internal examination of an artefact or to investigate concretions, x-radiographs can be used (Moore 2001).

Nowadays, digital technology provides more advanced and more objective methods than traditional illustrated drawings and photographs, which, depending of the creator, provide limited information for the technological features of the artefact (Abel *et al*. 2011).

More and more researchers are using 3D models to illustrate cultural heritage artefacts, especially due to the development of computer processors and increase of RAM size (Kaufman *et al.* 2015), in combination with the reduction of prices. These models can be saved in virtual archives for future generations (Schaich 2007). Many procedures have been used to 3D capture the upper surface of artefacts over the last years. According to many researchers, the most accurate methods to produce 3D models of the upper surface of an artefact are photogrammetry and 3D laser scanning (Ramón *et al*. 2013, Abel *et al*. 2011). For further investigation of the internal part of an artefact in 3D format, Computed Tomography is recommended (Abelt *et al*. 2011, Thiele *et al*. 2015).

1. Computed tomography (CT)

X-ray Computed Tomography (CT) is a method which was developed for medical imaging in 1975 to scan living patients (Cox 2015, Weber 2014). It is a non-invasive technique which creates 3D models of an object (Morigi *et al.* 2007). It uses X-rays to obtain cross-section images of an object through transmission or reflexion. The data are collected by illuminating the object from many directions (Kak & Slaney 2001, Ramón *et al.* 2013). The X-rays interact with electrons and the CT model that is created has different contrasts locally made by the differences in mass density and material of the object (Ramón *et al.* 2013). The resolution of a CT ranges from 1 mm to 200mm and a micro-CT from 1 mm to 100 mm, depending on the system and the size of the object (Weber 2014).

Both CT and micro-CT can give very good results on dense objects, such as bones, teeth, ivory, shells, stones and pottery (Weber 2014). Aside from the medical field, CT has been used for geological research, the determination of the brightness distribution over a celestial sphere and three-dimensional imaging with electron microscopy (Kak & Slaney 2001, Ramón *et al*. 2013).

In archaeology, researchers applied this technique in 1977 for the examination of a mummy (Cox 2015). Further research includes the scanning of brain tissue (Millet *et al.* 1983) and the reconstruction of facial features (Lewin *et al.* 1990). Since then the method has also been used for the examination and 3D reconstruction of ceramic vessels (Miles *et al.* 2016, Anderson & Fell 1995, Kotoula 2016), textile fabric (Shinoharal *et al.* 2006), rocks (Thiele *et al*. 2015), small paintings on wood (Morigi *et al*. 2007), wooden artefacts (Zhanga *et al.* 2012) and even for dating such artefacts by applying dendrochronology (Bill *et al.* 2012). Nevertheless, Computed Tomography is considered a high cost method (Kotoula 2015) with limitations regarding the size of the artefacts that can be imported into the device (Okochi *et al.* 2007).

2. Case Study

The artefact selected for this research was a 17^{th} century AD casket which belongs to the Anne of Cleves House Museum in Lewes, UK. The specific casket was considered suitable due to:

- the combination of different materials; wood as the basic material, with white decorative elements, metal, marble paper and oil paint. The variety of materials provides the opportunity to test the suitability of Computed Tomography as a 3D capturing technique in order to be used for conservation reports of complex artefacts.
- relatively small size which will allow it to be transferred and thoroughly analysed and scanned at the CT scanning facilities of the University of Southampton, μ-VIS X-Ray Imaging Centre.

2.a Description of the casket

According to the curator of the museum, throughout the artefact's history there had been neither scientific examination nor modern conservation treatment. Therefore, questions arise regarding the white material used for the external decoration (ivory bone or alabaster). Similarly, the type of wood used for the construction of the casket was unknown. The dimensions of the casket are 22 cm wide on the bottom and 25.5 cm on the lid, 14.6 cm long on the bottom and 18 cm on the lid, and 14 cm high with the lid.

The decoration is composed of architectural motifs (Fig. 1): eight white columns (1), four on the front and two on each side, and a white decorative plaquette reminiscent of floral decoration that covers almost 2/3 of the casket from top to bottom (2). The final third consists of four pseudo-drawers (3), two on the front and one on each side, with a white handle attached (4). At the centre of the front side, between the two central columns, is the place where a lock used to be (5).

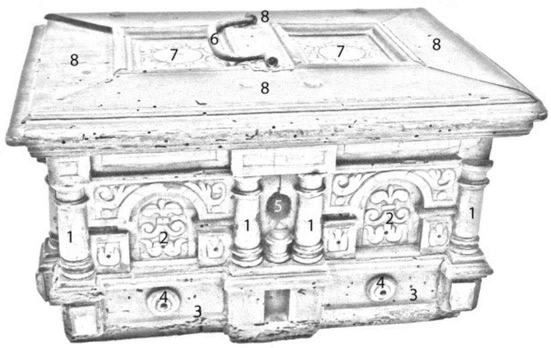

Figure 1 The front side of the casket.

On the lid a metal handle is located in the middle (6), adorned with one white plaquette with decorative pattern on the side (7). Four wooden parts and four nails compose the rest of the lid (8). The bottom has no special decoration and simply consists of three wooden pieces. Apart from the bottom, all the wooden parts of the casket have been painted probably with oil paint in a dark red/brown colour, covering also the metal nails and the handle, possibly as part of an old aesthetic restoration of the artefact. The right side of the casket is a partition (Fig. 2) with a size of 12.6 x 12.6 x 2.5 cm, which may be slid upwards when the lid is open revealing two secret drawers (Fig. 3) hidden behind it (1). The drawers have a size of 12.7 x 4.9 x 2.3 cm, and they are painted in an oil-green colour, decorated with marble paper inside. The two drawers are separated by a piece of flat wood painted with the same colour (2).

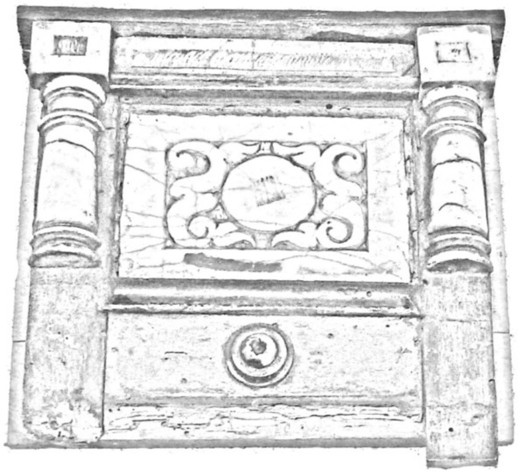

Figure 2 The side partition from the right side of the casket.

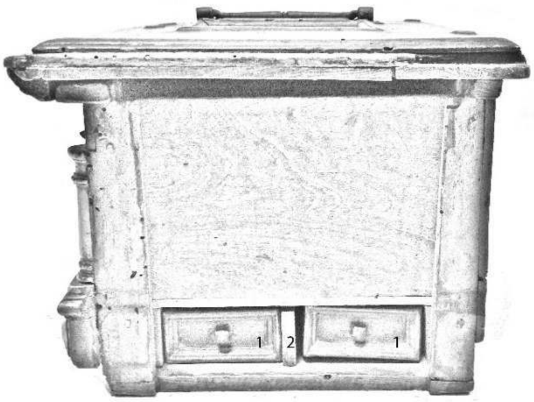

Figure 3 The right side of the casket.

When the lid is open (Fig. 4) two metal hinges are visible (1), part of the lock (2) and parts of the handle (3). Inside the casket on the left side there is a raised wooden box with a lid, with a size of 12.3 x 5.4 x 3.7 cm (4). All the interior surfaces of the casket and the raised box are covered with marbled paper except the surface under the raised box.

Figure 4 The interior part of the casket.

2.b Condition of the artefact

The general condition of the casket can be characterised as good (Krueger *et al.* 1994) since the materials appear stable and do not demonstrate signs of fragility. However, there are a few damages that are immediately visible:

I. Decay caused by biological factors.

The small holes on the wooden parts, mainly on the bottom and on the lid, are characteristic elements of insect infestation, probably woodworm, in the interior of the wood. In some areas, the phenomenon is more intense and there is a complete loss of wood. This is clearly visible on the front side under the left pseudo-drawer, where the wood looks like it used to be friable, and therefore it seems like varnish has been used in the past to make it stable again (Fig. 5).

Figure 5 Detail showing the loss of wood on the front side of the casket.

II. Decay caused by mechanical factors.

A lot of decorative parts have been detached over time; some of them are retained with potential for repositioning, but most of them are lost. Amongst the preserved parts a small white parallel-piped cube can be found with a size of 1.9 x 1.7 x 0.8 cm (possibly from the top right corner of the front side), a small piece of wood with a size of 6.8 x 1.4 x 0.8 cm (probably from the right external panel) and a bigger piece of wood with a size of 11 x 0.6 x 0.5 cm (probably from the panel of the back side) (Fig. 6).

Figure 6 The detached parts of the casket.

The missing parts include the locker, one of the four wooden parts of the lid (which now reveals a crack on the wooden base), two small wooden parts from the decoration on the front side, two white trapezoid shaped pieces from the lower front side and from the bottom half of the left column on the left side. On the back side a big wooden part at the bottom left side and a small part at the bottom right side are missing and the internal wood is visible.

When the casket is open, a big crack is visible, spanning from the right side to the left hinge. Both hinges, lock and handle are rusted. The paper is in a relatively good condition, although there are stains probably caused by humidity and a large missing piece on the right side of the casket.

2.c Possible origin of the casket

As it was mentioned before, there is no information about the history or the use of the artefact from the museum. While researching its origin, it was discovered that some auction houses had similar or near identical caskets and were characterised as a "17th Century Malines Alabaster & Ebonised Wood Casket". Derived from this "title" only the date had already been confirmed by the museum. Instead of ivory, alabaster seems to be the main decorative material, with origin from Malines (in French) or Mechelen (in Flemish) in Antwerp, Flanders, Belgium (Christie's 2010, Wilkinson's 2014).

3. Methodology

Before scanning the casket with the method of Computed Tomography, questions were raised regarding the exact interest of study, including:

- the structure of the casket
- the kind of materials used for the creation of the artefact (such as type of woods, binders, etc.)
- the thickness of the colour on the surface
- the material of the white decoration (whether it is ivory or alabaster).

To answer these questions, it was considered more appropriate to perform three scanning sessions: first the casket with the drawers and all the detached parts inside, second the side partition and third only the white cube. For the scanning of the casket with the Computed Tomography method the available scanner from the Department of Engineering Sciences of the University of Southampton was used. This scanner is a dual source 225/450kV walk-in room (Nikon Metrology, UK). The scans were acquired using a micro-focus 225kV source fitted with a tungsten reflection target together with a Perkin Elmer XRD 1621 detector. Table 1 shows the scan settings.

	kV	mA	Time exposure (ms)	Projections (360° rotation)	Voxel resolution
Casket	160	214	500	1571	329
Side partition	160	62	134	3142	102
Cube	160	62	134	3142	18.2

Table 1 Scan settings.

4. Results

The application of Computed Tomography resulted in detailed models of the casket and the detached parts, which addressed the research questions mentioned above. The results are analysed below.

4.a Results from the cube

The scanned images from the cube show a solid material with clearly visible small minerals inside. The images were compared to Lázničková-Galetová's (2015) research about an ivory necklace in order to determine if the material of the cube is ivory. Figures 7 and 8 render the difference between the ivory and the material of the cube obvious.

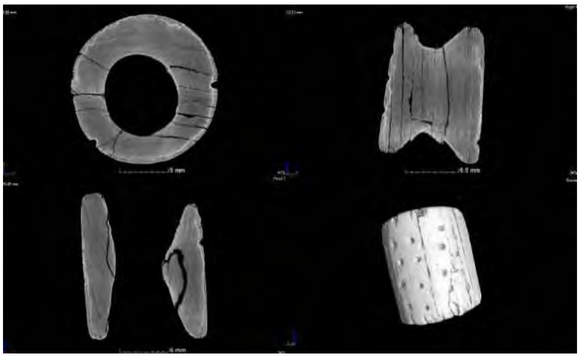

Figure 7 A micro CT image of an ivory part of a necklace (Laznickova-Galetova 2015).

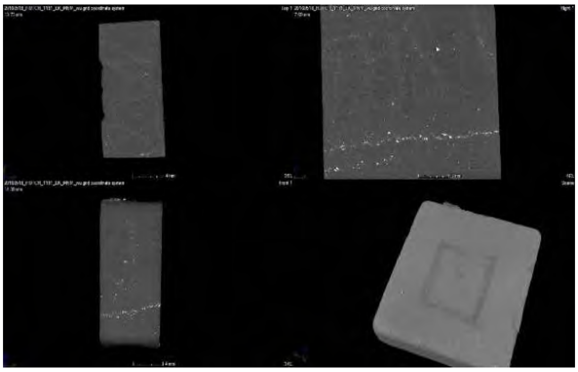

Figure 8 The CT image of the cube from the casket.

The ivory appears to have growth rings in its structure, similarly to other organic materials (for example wood). In contrast, the images of the cube differ due to the small stones or minerals on the interior surface. These minerals also seem to illuminate differently from the rest of the material.

This does not mean that it is a different material from the rest of the cube. It could mean that the "stones" are more compact in their structure and this is why they can be digitally isolated from the rest of the cube. In conclusion, from these images it seems that the material of the cube is not organic, so it is not ivory. Subsequently efforts were made to recognise what kind of inorganic material the cube is made of.

Unfortunately, there are no databases with CT images or papers with similar results available for a direct comparison. However, based on existing knowledge and with the employment of established techniques, such as digital microscopy, it was possible to compare the cube with other stone samples and conclude that the material of the cube, and therefore of the decorative material of the casket, is alabaster.

4.b Results from the side partition

The CT images from the side partition show that the condition can be characterised as good. Despite many insect holes inside the wood, these are mostly present at the framing and do not extend into the main wooden surface. Thus, there is no concern about the static maintenance of the object. Furthermore, it is visible that two different kinds of wood have been used to create the side partition. One for the top and one for the rest of the side partition. This is visible from the different tree rings and even from the colour of the wood (Fig. 9). Other visible information from the CT images is the manufacturing elements, as binder glue and metal nails were used for its manufacture. Glue was applied between the alabaster and the wood.

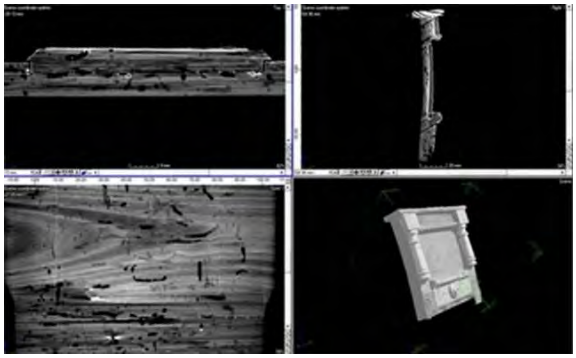

Figure 9 CT image showing the two different woods.

In some areas, the presence of large gaps between the two materials may cause detachment of the alabaster plaquette from the wood (Fig. 10). In other areas, the thickness of the glue was 1.30 mm. The second binding method was the use of three metallic nails to hold the pieces of wood together: one on the top in the middle with a diameter of 1.59 mm and length of 17.73 mm (Fig. 11), another also on the top but on the right side with a length of 5.29 mm and one on the bottom in the middle of the painted surface with a length of 8.37 mm. From the CT results the thickness of the paint is also visible. An example is presented in Figure 12, with a thickness of 0.38 mm.

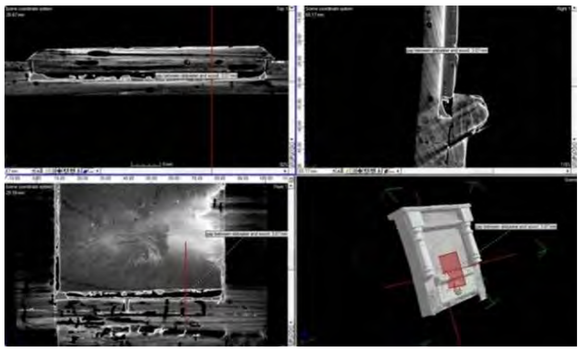

Figure 10 CT image showing the gap between the wood and the alabaster plaquette.

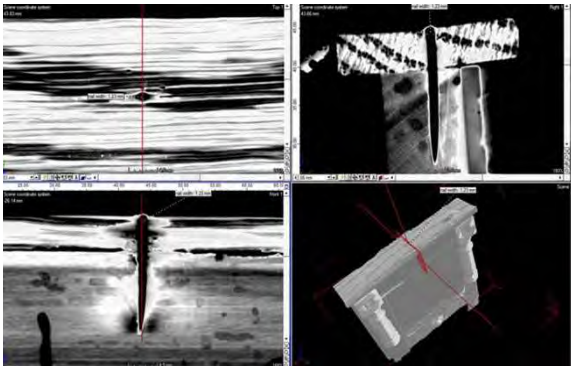

Figure 11 The metallic nail at the top and middle of the side partition.

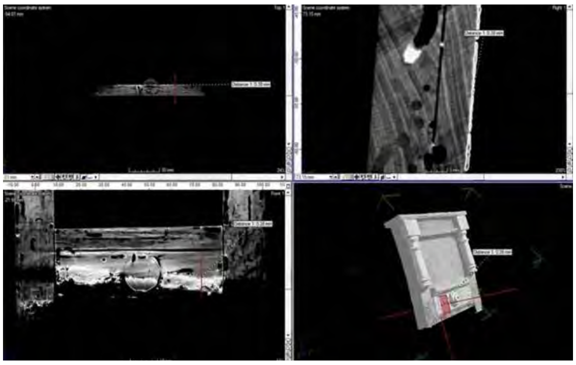

Figure 12 CT image where the thickness of the paint is visible.

Finally, all the different elements are presented in Figure 13 as they have been found. This provides a basic map of where the materials are located. The coloured surface had almost the same illumination as the alabaster making difficult for them to be separated. This might be because the red colour was probably made from inorganic materials (cinnabar HgS) (Elcher 2016).

Figure 13 The different materials of the side partition: metallic nails (blue), alabaster (white), oil paint (pink) and wood (brown).

4.c Results from the casket

Most of the information from the casket's structure was captured with detail in grey scale, especially the details from the alabaster decoration and wooden parts of the box (Fig. 14).

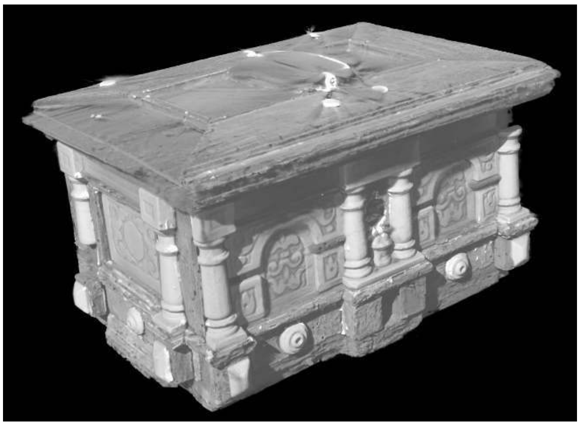

Figure 14 CT image with a perspective view of the casket (image by Mark Mavrogordato).

Among the other findings that the Computed Tomography revealed, a secret drawer was found behind the two other drawers. The "secret" drawer has a signature on the back, which unfortunately was not able to be deciphered with the methods used (Fig. 15-16).

Figure 15 The three drawers (top view).

Figure 16 The three drawers (bottom view).

As the CT images show, the drawer is connected with the other piece of wood with an adhesive (Fig. 17). The bright white parts around the drawer are due to the red paint on the front of the drawer. The maximum thickness of the paint is almost 1mm. The recorded data from the casket shows that in general the internal condition of the artefact is very good, specifically regarding damages from insects. Particularly the front side of the casket has many insect holes, which makes the area vulnerable and requires immediate treatment, especially close to the missing part of wood (Fig. 18). In comparison, the internal wooden part of the front side is in better condition than the external wood. The right side of the casket has only a few damages from insects compared with the other sides, probably due to the protection that the side partition provided for it (Fig. 19).

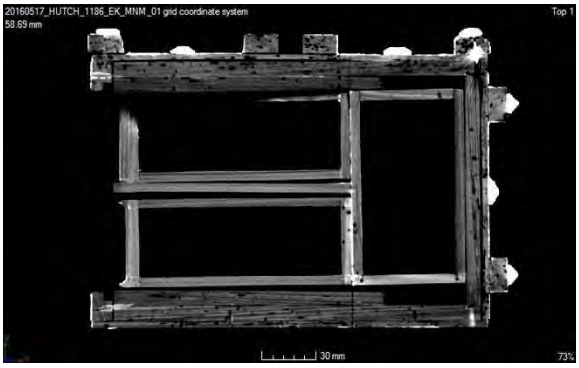

Figure 17 CT image which make visible the adhesive of the “secret” drawer.

Figure 18 Front side of the casket.

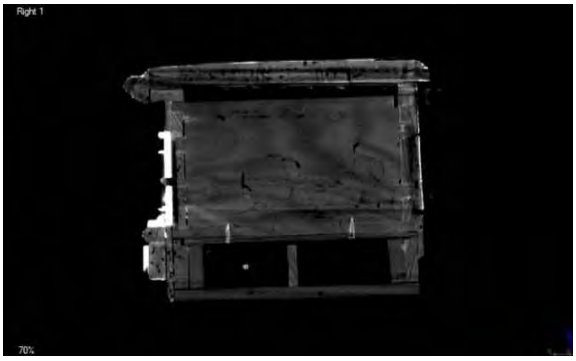

Figure 19 Right side of the casket.

The CT scan showed all the metal elements of the casket, both visible and those included in the structure (Fig. 20). Particularly interesting is the remaining part of the lock inside the wood. Other metallic elements were the nails which connect the internal bottom of the casket with its wooden walls. On the lid the CT image showed that there are in total 14 nails, with sizes between 10.86 to 14.35 mm.

Figure 20 All the metallic elements of the casket.

Finally, the nails which connect the bottom of the casket with the wooden walls are three on front side and three on the back with a width between 17 and 20 mm.

On Figure 21 all the different materials of the casket are visualised with different colours. In this case, the painted surface was not so easily separated from the wood, and it is illustrated with a white colour on the wooden surface.

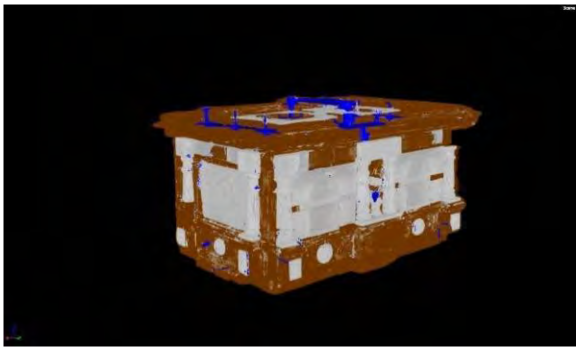

Figure 21 All the different materials of the casket: metallic elements (blue), alabaster (white), oil paint (white on brown) and wood (brown).

Conclusion

The technology of Computed Tomography can provide accurate results of the external and internal structure of an artefact, incomparable to the other 3D recording techniques, but it is not very easy to be used for condition reports. The main limitations are the lack of colour information (1), the high cost and level of expertise needed (2), the absence of portable equipment for data capture (3), the time-consuming data capture and processing required (4) and the large file size of the resulting models (5). The results are visualised in a grey scale colour, which means that the external surface does not portray the original colours of the artefact, an important factor for condition reports. It is an expensive method to use and it requires specialised staff to use the scanner. It is not portable and so that the object must be in good enough condition to be moved and it requires to be of a specific size for fitting inside the scanner. It is considered a time-consuming application, if it takes into account the time needed for the object to be moved to the computed tomography lab and the time spent on both the recording process and the time to learn and apply the data processing in advanced software.

Especially for projects where condition reports for large collections are commissioned and there is a limitation of time, it would be inconvenient for these 3D capturing applications to be used. The time it takes between taking pictures of an object and making 3D models cannot be compared. Furthermore, the acquisition of a specific equipment for the data process (software and high performance computer) can be restricted for some organisations, museums or individual conservators. Also, the cost of saving all these data must be considered. The space on the hard drive for saving a comprehensive condition report with traditional means can be a few MB, while a conservation report with 3D models can reach many GB, in this case was 70 GB. However, Computed Tomography is a very beneficial recording method for conservation condition reports. Nonetheless, this application provides a great solution when a more complicated artefact requires extensive research prior to applying more suitable conservation treatments. Having a record of the internal condition of an artefact can help conservators to recognise the wear mechanism of the artefact and finally to choose more appropriate treatments for the conservation. In this case, the results were used for the identification of materials and recording of damages and structure, revealing also secret construction components.

Future work

Computed Tomography is a new application for conservators which brings to light certain questions; can all conservators understand what exactly they see in the recorded data? And even if a material is scanned, is it easy to recognise what kind of material it is?

In this case study, the material of the cube was confirmed based on a detailed 3D model of the cube, visual inspection and previous research in the field. However, the exact type of the material (alabaster) is a speculation based on the descriptions of similar artefacts since only destructive methods of analysis can identify the exact type of stone material. In order for conservators to be able to use all the available features of Computed Tomography to their full potential, further research is proposed in order to create an analytical database including scanned samples for all the types of materials that were used or could have been used in an artefact's industry. This database has to include not only pictures of the materials but also the density of each material, presenting the histogram of the brightness and contrast adjustment in order to understand more about the origin of its material, like in this case the oil paint. Considering that until now only the density of air and water are known from previous work on medical Computed Tomography (Mavrogordato, personal communication), the proposed database signals a step forward both for CT technology and cultural heritage.

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USERS AND INTERFACES

EDUCATION, MUSEUMS AND MULTIMEDIA

BRESCIA-BRIXIA (ITALY). TRAVELLING THROUGH ANCIENT LANDSCAPES: THE CITY MUSEUM AND NEARBY ARCHAEOLOGICAL AREAS, RESEARCH AND ENHANCEMENT

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Περίληψη/Abstract

Στόχος του άρθρου είναι η παρουσίαση του έργου ανάδειξης της αρχαιολογικής κληρονομιάς της Brescia (Ιταλία) βάσει της προσπάθειας αναπαράστασης του τοπίου της αρχαίας πόλης μέσω της χρήσης νέων τεχνολογιών. Αρχαιολογικές ανασκαφικές έρευνες στην περιοχή έχουν προσφέρει επαρκή στοιχεία για την πλήρη μελέτη και ανασύνθεση του αρχαίου τοπίου, με αποτέλεσμα να είναι τώρα εφικτή η έκθεση εξαίσιων αρχιτεκτονικών προτάσεων, όχι μόνο για την προστασία διαφορετικών αρχαίων στρωμάτων αλλά και για την ενδυνάμωση της αξίας τους στο παρόν. Δοκιμάστηκαν πειραματικά διαφορετικά εργαλεία για την παρουσίαση της περιοχής και του αρχαίου τοπίου στο κοινό και διερευνήθηκαν διαφορετικές τεχνολογικές λύσεις για να επιλεγεί η προσφορότερη για τις ανάγκες των επισκεπτών: ένα βίντεο που λειτουργεί ως μηχανή χρόνου που ταξιδεύει δια μέσου των εποχών, ειδικοί φακοί για την προβολή επαυξημένης πραγματικότητας επάνω στο φυσικό τοπίο, καθώς και συσκευές εικονικής πραγματικότητας για την παρουσίαση του αρχαίου τοπίου της Brixia σε απομακρυσμένο ακροατήριο.

This paper presents an ongoing project to enhance the archaeological heritage of Brescia (Italy) by re-creating the ancient urban landscape using contemporary technologies. By means of extensive archaeological excavations the ancient landscape has been thoroughly studied and understood in detail; it is now on public display within exemplary architectural solutions which protect the ancient remains and enable their valorisation. Various tools have been tested to present the archaeological areas and ancient city to the public and different technological proposals were assessed in order to select those most appropriate for communicating with visitors: a video operating like a time-machine across the ages, special glasses with augmented reality overlaying the natural landscape, as well as virtual reality devices to present Brixia's ancient landscapes to a remote audience.

Keywords: Archaeology, Augmented Reality, Virtual Reality, Enhancement, Brescia

Introduction

The ancient town of Brescia, named Brixia two thousand years ago by the Romans, is located about 90 km from Milan. The site has been inhabited since the 3rd millennium BC; the remains of Roman Brescia are still very well preserved in the heart of the city centre and form an urban archaeological park.

The *City Museum* is housed in the monumental complex of Santa Giulia, a female monastery built in the 8th century AD and enriched with further structures and decorations until the 15th century AD (Stradiotti 2001, Brogiolo & Morandini 2014).

In this large area, at the junction between the lower hillside and the plain, ancient Brescia's historic monuments are concentrated in an uninterrupted sequence of buildings and layers conserved at different levels (Rossi 2014) (Fig. 1).

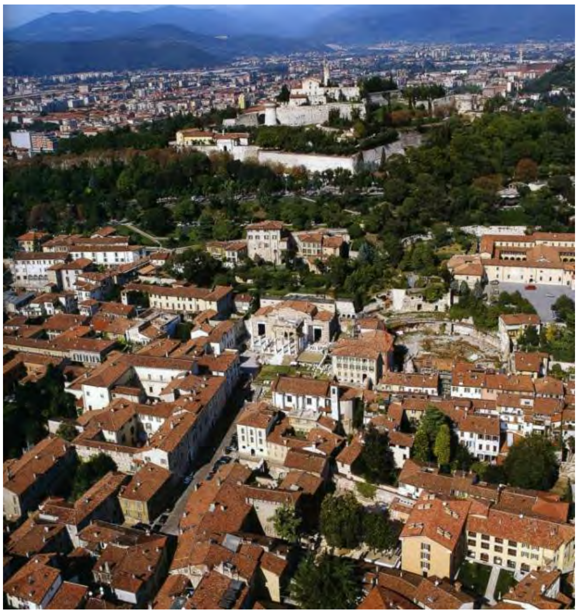

Figure 1 Aerial view of the city centre showing the archaeological area.

1. Research and enhancement project

Following a long-established tradition of interest for the care of archaeological heritage (shown by Brescian institutions since 1480), the Brescia Council, the Archaeological Superintendency of the Italian Ministry of Cultural Heritage, Activities and Tourism, the Brescia Museums Foundation, together with the Lombardy Regional Authority, launched an ambitious project to give back to the city its ancient core and to make it accessible to everyone (Morandini 2016).

Thus, both the archaeological area and Santa Giulia monastery complex have been undergoing progressive development work for nearly 20 years. It should also be noted that both places were listed as UNESCO World Heritage in 2011, in the serial site “Longobards in Italy. Places of the Power (AD 568-774)” (Morandini 2015).

Archaeological excavations in the Capitolium area brought to light an uninterrupted sequence of religious buildings dating from the 4th century BC to the 1st century AD, yielding very important information about the history, religion and architecture of the site, which is unlike any other in Northern Italy. Archaeological data were refined by a research team with diverse, but complementary, skills with the aim of summarizing and representing life in the ancient city across the centuries, so as to offer visitors a high-level presentation which is nevertheless readily accessible.

Thus, the ancient landscape was studied in depth and is now on public display within excellent architectural solutions which protect the ancient remains and enable their valorisation (Morandini & Rossi 2015).

2. Operating methods and instruments

Various tools – operating at different levels – are now available to present the archaeological area and ancient landscape to the public, based on the following documentary base:

- detailed specialist publications with phase drawings (Rossi 2014);
- 3D reconstructions of the natural scenery and buildings, combining photographs, drawings and sketches, developed from archaeological records (Fig. 2-3).

These documents are the foundation on which the project is based; different technological solutions derived from them were evaluated in order to select the tools which best targeted our visitors.

We worked on (a) video, (b) virtual reality devices and (c) innovative editorial products.

Figure 2 3D reconstruction of the city in Roman times.

Figure 3 3D reconstruction of the 2nd century BC temple.

(a) The video operates like a time machine across the ages and offers visitors a journey through the centuries while they are waiting to enter an underground part of the archaeological area (Fig. 4).

On conservation grounds, visitors must wait a few minutes before entering a temple dating to the beginning of the 1st century BC. This provides a valuable opportunity to appreciate the history of the place, the site's outstanding importance and the sequence of religious buildings. By means of video projection – which takes visitors back in time through images – we avoid encumbering the itinerary with explanatory apparatus, guaranteeing an uninterrupted view of the ancient remains and a direct approach without too much written information.

This video received the Gold Medal for Interactive Media at F@AIMP2.0 (Festival of Audiovisual International Multimedia Patrimony) organised by AVICOM (International Committee for Audio-visual and New Technologies for Image and Sound of the International Council of Museums) for the “Best product of the year in multimedia technology” (November 2016).

Figure 4 At the entrance to the archaeological area a video illustrates the development of the site and monuments through time.

(b) Virtual Reality devices are very useful for presenting *Brixia*'s ancient urban landscape at other venues. The use of Samsung Gear VR Apps produced by Carraro Lab, allows visitors to access 360° pictures, videos and 3D reconstructions of ancient Brescia, immersed in their surroundings (CarraroLab 2017). These might be used in a classroom or in another museum to present the city's archaeological heritage and its ancient landscape. These devices enabled Brescia to present its ancient patrimony in Milan during EXPO 2015, where they received very positive feedback from thousands of people.

(c) Innovative editorial products: in a guide book on the archaeological area there are QR-codes that activate external contents, e.g. 360° 3D reconstructions and videos, offering a high-quality visit before reaching Brescia, or after having been there (Fig. 5). These are especially valuable for those people who will never visit the area (Morandini & Rossi 2015). All the contents have been uploaded onto an upgradable platform.

Figure 5 One of the publications on the archaeological area, with QR-codes.

Furthermore, a particular focus of our efforts was the development of Augmented Reality glasses provided with an audio guide, to be used by visitors inside the archaeological area. Although the archaeological area is very well preserved, the temporal sequence of the remains may not be clear to all visitors. For this reason, we felt that it was important to identify the best tool to resolve this problem. The availability of a large number of 3D reconstructions ready for use in an immersive visit – without any alteration to the ancient monuments – led us to experiment with Augmented Reality.

In collaboration with ArtGlass, a group that supports the development of cultural organisations with up to 300,000 users in 14 projects, the museum started to design this special visit (ArtGlass 2017). By means of a software platform that integrates cultural heritage Augmented Reality content with wearable devices, visitors can enjoy a mixture of real and virtual and interact with the ancient monuments (Fig. 6-7).

Figure 6 Visitors wearing ArtGlass spectacles.

Figure 7 Real picture (left) and Virtual Reality reconstruction (right) of the Capitolium temple in Brescia-*Brixia* (1st century AD).

These devices are latest generation smart glasses and can be adapted to different solutions on cultural sites. Visitors are guided along an itinerary through the area by an audio narrative (available in various languages) and are invited during the visit to look at particular details or shapes. These function as markers and activate Augmented Realty contents.

The device overlays 3D reconstructions and dynamic videos onto the actual surroundings, rendering the ancient buildings as they were in the past, while avoiding any technical or direct interventions on ancient walls or decorations.

Using a common smartphone while walking, additional content is automatically activated on the glasses, such as a historical image of the archaeological excavations overlying the ruins in view, a short video showing the interior of the Republican temple (Fig. 8) or 3D reconstructions of the monumental complex during the Roman Imperial age - with the Capitolium, Forum and Basilica together with the hill surmounted by another temple, and the city walls. The latter content enables visitors to experience walking through the ancient city and enjoy, after nearly two thousand years, the original urban landscape of Roman *Brixia*.

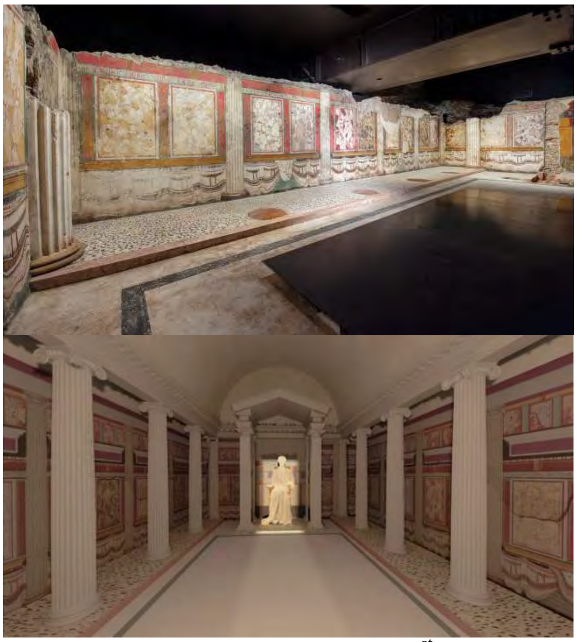

Figure 8 Interior view of the early 1st century BC temple (above); 3D reconstruction of the temple, complete with cult statue and decoration (below).

By means of the smart glasses, visitors learn about different hypotheses regarding the original buildings and become aware of the methods used by researchers in archaeology. As most of these tools have been used in an archaeological area for the first time, we have established a test period involving visitors, during which hardware and software may be revised in an effort to improve.

Visitors are asked to fill out forms, leaving their comments and suggestions to improve device performance and content quality. Following their suggestions, we hope not only to improve the tools at hand, i.e. their ease of use and clarity, but also reconsider their rental fee.

3. Evaluation of the experience

The experiment conducted in Brescia has been greatly appreciated by visitors, since all devices are user-friendly, furnish interesting information and entertain. In addition, all researchers involved in the project were greatly satisfied, because all the data derived from archaeological excavations were accurately reproduced and used to inform conservation interventions and strategies.

These technologies open up new paths to the enhancement of archaeological heritage. Actual reconstruction of monuments is made redundant, as visitors can enjoy the view of alternative virtual 3D reconstruction proposals, discuss them and decide which they prefer. Besides, these media can include further alterations or improvements on the basis of new research studies and new 3D reconstructions.

Another advantage of this technology relates to the accessibility of the content, especially to people coming from different countries and cultures. These tools were made available during the 2015 EXPO, when many tourists from all over the globe came to visit museums and archaeological areas in Brescia. By avoiding ordinary texts and drawings, and using images and audio in different languages instead, it was easier for a diverse audience to understand the shape of a Roman city, its main monuments and the quality of their decorations. Listening to a story that takes the visitor travelling through the centuries was appreciated by most, children or adults.

4. Current and future plans

These encouraging results led us together with the same team (ArtGlass) to apply the same strategy to another archaeological area within the City Museum: the so-called “convent-garden houses”, two excavated Imperial Roman period dwellings that were opened to the public in 2003. This area became part of the museum after two years of archaeological excavation and research; visitors to the site walk on a raised pathway (thus avoiding direct contact with the ancient structures), enjoying the impressive remains of those two houses dating to the 1st and 2nd centuries AD (Morandini 2003).

At present, labels, drawings, texts and a short video are available to visitors. In 2017, we will be able to offer a visit with AR, representing the dwellings from above, opening their roofs and showing the houses from inside, just as they looked in Roman times. As already mentioned for the previous archaeological area, the virtual reconstructions are based on the detailed studies produced at the end of fieldwork research (Figs. 9-10).

Our next step targets the introduction of the same technology in the Early Medieval church of San Salvatore, also to be found within the City Museum (Brogiolo & Morandini 2014). Using the smart glasses people will see the walls decorated with intact frescoes as well as the original marble ornamentation, and once again will travel through the ages (Figs. 11-12).

Figure 9 Interior view of one of the "convent-garden domus"; in the foreground, a room with floor and ceiling (1st century AD).

Figure 10 View of the ceiling of the room looking upwards (3D reconstruction).

Figure 11 San Salvatore: internal view.

Figure 12 San Salvatore: detail of stucco decoration between nave and side aisle.

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PUTTING CASUAL GAMING IN HERITAGE INTERPRETATION: "THE URBAN GAME [BETA]" EXPERIENCE

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Περίληψη/Abstract

Η πολιτιστική πρωτοβουλία "The Urban Game [BETA]" ξεκίνησε το Μάιο του 2016, στον αρχαιολογικό χώρο των νεωσοίκων της Ζέας, στον Πειραιά. Κύριος στόχος της είναι να επαναπροσδιορίσει τη σχέση μεταξύ ξεχασμένων χώρων μνήμης και παρόντος, εισάγοντας μια νέα χωρική διάσταση μέσω του gaming και προβολών ψηφιακών έργων τέχνης. Εκμεταλλευόμενοι τη δυνατότητα που παρέχουν τα παιχνίδια στο να οδηγούν τον εκάστοτε παίκτη προς ένα συγκεκριμένο στόχο, δημιουργήθηκαν παιχνίδια τύπου "casual", τα οποία είχαν ως σκοπό την εμπλοκή του χρήστη σε μία σειρά επίτευξης στόχων, μέσα από τους οποίους είχε τη δυνατότητα να αντλήσει πληροφορίες για το χώρο και να παρατηρήσει αρχιτεκτονικά κατάλοιπα κάτω από τις σύγχρονες δομές, μέσα από ένα περιβάλλον επαυξημένης πραγματικότητας. Στην παρούσα εργασία, συζητούνται τα αποτελέσματα του "Urban Game", κατά την πιλοτική του εφαρμογή, σχετικά με το ρόλο των "casual games" στην ενίσχυση της εμπειρίας των επισκεπτών και τη σύνδεση εκπαίδευσης και πολιτισμού.

The "Urban Game [BETA]" is a cultural initiative that was launched in May 2016, at the Zea ancient shipsheds of Piraeus. Its main goal is to redefine the relation between forgotten places of memory and the present, by introducing a new spatial dimension produced mainly by gaming and digital art projections. Taking advantage of the ability of games to lead the player achieve a specific goal, "casual games" were designed aiming at engaging the users in a number of quests through which they were able to acquire information about the site and observe architectural remains under modern structures, through an Augmented Reality environment. In this paper, the results of "The Urban Game [BETA]" will be discussed, regarding the role of casual gaming in enhancing visitors' experience and connecting education and culture.

Keywords: Gaming, Casual Games, Heritage Interpretation, Zea Shipsheds

Introduction

Computer-based games can be generally described as challenges that require specific strategies to be adopted by a player so as to achieve certain goals, while the outcome has no impact to their physical environment. Furthermore, they have been considered as knowledge-seeking activities to the extent that this "knowledge is reached because of activity and during activity" (Champion 2016). Games have the ability to turn somebody into an active participant rather than a passive recipient of information, triggering their creativity and imagination.

Over the last years, an increasing number of museums and cultural institutions have been trying to exploit this potential of games in order to present historical and archaeological information to contemporary visitors and to activate the individual's sensorial acts, physical reactions and cognitive mechanisms through the creation of an immersive experience (Aydin & Schnabel 2016). Gaming has surpassed the field of leisure activities and has been used for heritage and educational purposes, usually connected with Augmented Reality (AR) and Virtual Reality (VR) applications (Champion 2011, Renevier *et al.* 2005) and the creation of serious games (Anderson *et al.* 2010). These techniques have been used as a medium in order to improve a visitor's spatial experience, by rethinking the ways they can interact with a site or an exhibit and the information they can obtain. Two basic observations leading to this approach have been the decreasing number of visitors of younger age and the so called "museum fatigue" phenomenon (Avouris *et al.* 2014, Bitgood 2009). At the same time, studies have shown the importance of such applications in learning processes by increasing motivation, attention and encouraging social interaction (Economou & Pujol 2011, Pujol & Economou 2008). However, casual gaming applications seem to have been less explored in similar contexts.

Even though in the last few years casual gaming has appeared as a major trend in gaming industry, to date there has not been a satisfactory definition of casual playing. "Casual" remains a complex concept that is connected not only with certain features of games but also with certain attributes of game players (Mäyrä 2015). Chiapello (2013) suggested that successful casual games should be challenging, but not of high difficulty, retaining a balance at the ratio between challenge and skills. Adams (2002) attempted a distinction between hardcore and casual gamers, based on a list of 15 weighted variables that could profile a gamer through qualitative measurements. Among others, these included playing games over long sessions, comparative knowledge of the industry, preference on game complexity and familiarity with game-technology advances.

More often than not, when talking about casual games, we mean games that are used by mass audiences, usually on-line or on mobile devices, with not much attention being paid on the genre of the game (e.g. puzzle and card games, strategy, adventure etc.). In contrast to hardcore games, i.e. games that are characterised by more complexity, higher competition and require a more advanced skill-set, casual games are characterised by simpler rules and more friendly interfaces, while they are easier to control and do not require a long-term commitment in order to be accomplished. Mäyrä (2015) also provides a more detailed list of casual games characteristics, based on the GameSpace project data.

In the present paper, some preliminary results and conclusions of "The Urban Game [BETA]" project are presented, regarding the role of casual gaming in enhancing visitors' experience.

1. Aims of the project

The "Urban Game" cultural initiative was launched in May 2016 as a pilot version (BETA). Based on international practices (ICOMOS 2008) and interpretation approaches (Brochu & Merriman 2002, Tilden 1977), its overall aim is to re-introduce local communities to important, yet forgotten, monuments and sites of their region that have fallen into oblivion, because of the city's incapability to integrate them in the urban fabric. Consequently, the main objectives are to raise public awareness and render those "urban voids" integral parts of the urban fabric. The idea is to make those places accessible to the public, by organizing an event and turning them into lively places of social interaction and knowledge. People will have the opportunity to get acquainted with little-known monuments of their region through an educative and creative process, while the place that hosts the event is "re-activated", proving that can be an essential part of a modern city. The means employed for this purpose are gaming and gamification techniques supplemented by AR features along with digital art projections.

Gaming was chosen to complement the event for two main reasons. The first reason is its popularity – especially among younger people (Anderson *et al.* 2010) – and presence in everyday life, mostly through social media and mobile apps. In particular, mobile games are being adopted by more and more people as they can be played irrelevantly of the location and circumstances (Leaver & Wilson 2016). The second reason is the ability of games to lead players towards achieving a specific target; in our case to get acquainted with a monument. Through a gamified experience the player might feel free to act independently, but in reality their decisions are based on directions imposed by a computer system with strict rules and limitations, so that gradually they become part of that system. As a result, players become the subject of an illusory freedom, which may render their experience personalised and unique, but in effect it leads them to think over and react in a particular way and have specific targets.

Next to gaming, a simple Augmented Reality application was developed as the most appropriate medium in order to present any remaining architectural features. Augmented Reality (AR) adds data, such as virtual objects and labels, in order to enhance the real world and amplify the perception someone has on reality, thus making it ideal for presenting archaeological sites and monuments to a wider public.

2. The Site

The first monument to implement the concept described above was the archaeological site of the ancient shipsheds at the port of Zea, in Piraeus. Piraeus was largely developed in the early 5th century BC, when nominated as the port city of Athens and turned into a major commercial and military center, taking advantage of its three natural harbours. Zea was the main harbour to host the Athenian fleet.

The shipsheds found in this area were oblong structures, sheltering a leaning slide for the hoisting and launching of the ships, separated by rows of pillars. They were originally built to house triremes so as to protect them from weather conditions and conduct the necessary reparation works. According to archaeological evidence and literary sources, by the end of the 4th century BC there were 196 shipsheds at the Zea harbour (Lovén 2011, Pakkanen 2013).

The best-preserved part of the site, where the "Urban Game [BETA]" took place, is today secluded inside a small pilotis alongside the foundation of the superimposed buildings (Fig. 1). The site confronts severe conservation problems, related mostly to humidity. Even more, it is always closed to the public. As a result, next to conservation issues, most of the local population is unaware of its existence, missing an important part of their city's history.

Figure 1 The archaeological site in the pilotis of a school yard.

3. The Games

The games that were used, during the pilot implementation of "The Urban Game", belong to some of the typical genres that fall in the "casual gaming" category, while at the same time, in order to enhance people's interest, "escape room" riddles were incorporated in the app. These specific game genres were thought to be the most appropriate for the pilot version, as a simply structured medium of interpretation and provision of information in order to improve visitors' experience. Those games were inspired by elements of the archaeology and history of the site and were no different than games most people are used to playing online or on their mobile devices. More specifically, these included:

- Sliding Puzzle games that depicted pictures corresponding to the reconstructed views of the monument (Fig. 2) or other images related to it, such as triremes, the ancient Greek warships.

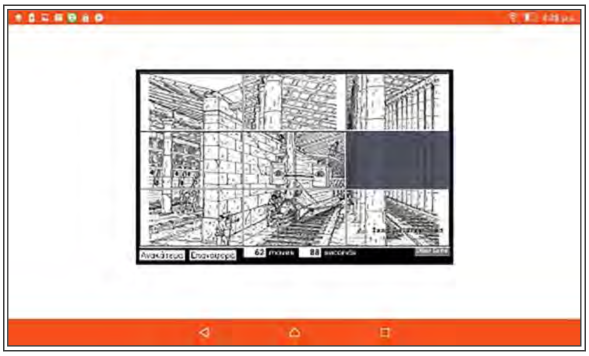

Figure 2 Screenshot of a sliding puzzle game.

- Riddles that could be solved by acquiring "clues" throughout the game, which were connected in one way or another to the history of the site or the shipsheds themselves (Fig. 3).
- A Mine Sweeper game, through which players were able to deduce which parts of the site were later additions and do not form part of the original monument.
- An orientation game using an image of the original measured drawings made by Wilhelm Dörpfeld helping players understand their location inside the urban context.

Figure 3 A young visitor trying to solve a riddle.

- A memory double card game (Fig. 4), which, when successfully completed, revealed to players the location of parts of the monument that are buried under the pedestrian street of Akti Moutsopoulou, allowing their view using an AR feature.

Figure 4 Screenshot of a memory double card game.

Maps of the area, images from past excavations, architectural and archaeological drawings were employed, so as to reconstruct the floor plan of the site, put it in the context of the modern urban fabric and integrate both in the design of the games and the AR application (Fig. 5).

Figure 5 The app interface and main menu (in Greek).

All visitors had the option to download the app on their devices or use it on tablets available on site. The menu of the app was available in both Greek and English. Through this app they could undertake a tour themselves and get information about the site by playing the games. If a game was successfully completed, players were awarded with a badge that unlocked levels of higher difficulty, a classic means of gamification that pushes people towards trying to get a 100% completion percentage. At the same time, they had the chance to discover a part of the archaeology and history of the site, either by watching a video or by observing features through the AR environment. Every time they completed one of the games they had to move to another spot in order to continue and learn more about the shipsheds. Quick Response (QR) codes were helping them to initiate their game, find the hidden remains under modern structures and get informed about the digital artworks that were displayed on site. Even though there was a proposed route and use for the application, visitors were free to use it in their own fashion, skipping some games and use it only to observe features and get information about the site and digital art works (Fig. 6).

Figure 6 Visitors using the app and interacting with the monument and the digital art projections.

4. Results

Observations and informal post-experience interviews were employed to understand the contribution of casual gaming in the context of such an event and its role as a medium for public engagement, especially among younger audiences. User-based evaluations for the revision of multimedia methods in cultural heritage are important for the future success of such applications, not only with regard to their technical aspects but also for visitor engagement (Chrysanthi *et al.* 2013, Champion 2016). Although, in our case, there were no structured questionnaires, we had the opportunity to get some preliminary results and ideas on the use of casual games in heritage interpretation.

The event lasted 9 days, during which 504 people visited the site. About 200 of them participated in the informal interviews. The age of participants ranged from 7 to 62 years. Just under a half of them were school students and nearly a third were between 18-30 years old. The significant majority were locals or from nearby regions, while a small minority were tourists.

Despite the fact that all visitors used the application, this game-based approach appeared to be particularly appealing to children and young people. Underage visitors seemed more willing to follow the proposed steps, which meant scanning all QR codes and trying to complete all different difficulty levels, as well as discovering as much information as possible. Consequently, they spent more time playing the games and using the application. In contrast, most adult visitors focused on watching the videos and retrieving information about the site and the digital artworks.

It is worth mentioning that although visitors aged up to around 40-45 years were more comfortable with using the application independently (as expected at some level), visitors exceeding that age also expressed their interest in learning to use the app, even with some help from the supporting staff of the event. However, as a general observation, it can be supported that most of the visitors found it quite easy to interact with the app interface and play the games without any further guidance.

The informal discussions with the participants, after their visit, had a basic usability testing character and were mostly targeted in acquiring some feedback on the design of the games and their contribution in the visitors' overall experience. Most people under 25 years old described the games as “fun” and “easy to follow” or just “interesting”. Users of younger age, mostly adolescents and children, although attracted by the games, they considered them to be “sometimes easier and simpler than they should” and expected the games to be “more challenging”. On the other hand, a significant number of adult visitors seemed to enjoy these games since, in contrast with most VR and AR games used in heritage, “they did not require a high skill set to play” and “the interface was familiar”. As a result, they could easily find their way and use the app. Some of the visitors also expressed their content, regarding the communication of archaeological information through multimedia methods. In addition, almost every child or adolescent that participated in our survey said that they had acquired at least one piece of information about the site and its use during the ancient times.

5. Discussion

Even though a structured user evaluation was not intended during this pilot version of the “Urban Game”, it was possible to reach some interesting deductions pertaining to the implementation of casual games in heritage interpretation and to examine their potential in the heritage sector. Casual games appear to be an appropriate medium to communicate historical and archaeological information, either during the activity or after the activity, through texts, images and videos. Their familiar interface and simple control demand minimum effort by the players/visitors, thus giving them the chance to focus on the content. By being aware of what needs to be done, the players feel receptive to additional information content. However, when it comes to the presentation of archaeological remains, an AR or VR application seems to be not only more effective than traditional display methods and simple game interfaces, but also essential and, at some point, anticipated by the visitors.

Through their popularity and "simplicity", casual games can reach much wider audiences than just young or computer literate people, including visitors of older age; an important aspect when disseminating cultural content. This could potentially help bridge the gap between "digital immigrants" and "digital natives" (Prensky 2001). Studies, investigating video-game playing as a form of cultural consumption, have shown that video-gamers are not necessarily of a younger age or of a specific gender. Although game playing is more appealing to younger cohorts, even older people can enjoy video-games regularly, provided that the technological barrier is removed. Such being the case, we have to consider the heterogeneity of the players (Borowiecki & Prieto-Rodriguez 2014). Nevertheless, the challenging character of the games should not be overlooked in favor of an intuitive app environment.

Even more, casual games give the possibility to employ the advantages of mobile technologies in heritage. As other mobile games, namely those played on smartphones or tablets, casual games give the potential of engagement with the surrounding environment. This attribute is particularly important in cases where visitors are not being static and move around a site or an urban space, rather than being limited within a controlled environment, like a museum. In addition, they seem to be an inexpensive and relatively fast process, since the development of a casual game can be a matter of months. On the other hand, the challenge is to catch up with constant developments, since casual gaming is a rapidly and continuously advancing field, demanding regular evaluation of any application that becomes available.

A concern that arises is that games have the potential to allow players "explore more complex systems rather than simply follow a linear narrative". However, to date, no concrete guidelines exist on how to create successful games for heritage (Goins *et al.* 2015). For this reason, evaluation in every level, from design to implementation, is necessary. Next to usability testing, usability inspection methods would be of equal importance, so as to identify any problems and improve the user interface design (Karoulis *et al.* 2006). Heuristic evaluations, based on accepted usability principles as released by Nielsen (1994), have been broadly implemented in early stages of game design. They form an appropriate method to be combined with other user-based methodologies in order to provide relatively quick and inexpensive feedback to interested parties (Pinelle *et al.* 2008, Sutcliffe & Gault 2004).

Conclusion

Taking into account the results from our observations and the discussions with the visitors, this early stage evaluation can help us improve the application and its underlying concept, so as to be more fulfilling to its educational and learning purposes and more attractive to a greater audience, regardless of age. Even though the results are preliminary and the application is in need of improvement, the aforementioned approach verified the contribution of technology in non-formal learning and introduced casual gaming in heritage interpretation as an uncomplicated and understandable medium. Even more, it demonstrated that similar attempts can be more successful, in terms of visitors' engagement, when trying to keep it simple and implementing techniques and patterns that most people are familiar with.

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HAGIA SOPHIA: 1500 YEARS OF HISTORY, A DIGITAL RECONSTRUCTION

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Περίληψη/Abstract

Αντικείμενο της παρούσας εργασίας αποτελεί η παραγωγή εικονικής πραγματικότητας “Αγία Σοφία: 1500 χρόνια Ιστορίας”. Εστιάζει στη δημιουργία των τρισδιάστατων χαρακτήρων μέσα από τις πηγές και τα αρχαιολογικά ευρήματα, στην ανάπτυξη του ψηφιακού μοντέλου του ναού σε τρεις διαφορετικές περιόδους του Βυζαντίου και στη διαμόρφωση του ψυχαγωγικού και εκπαιδευτικού χαρακτήρα της τελικής παραγωγής. Αναλύονται τα προβλήματα που προέκυψαν κατά τη δημιουργία των ψηφιακών μοντέλων και οι λύσεις που προκρίθηκαν. Περιγράφονται οι τεχνικοί περιορισμοί του μέσου της παραγωγής και αναδεικνύεται η καθοριστική τους επίδραση στο τελικό οπτικό αποτέλεσμα. Τέλος, γίνεται σύντομη αναφορά στο προγραμματιστικό σκέλος της παραγωγής. Το τελικό αποτέλεσμα της παραγωγής επιδιώκει να ταξιδέψει το θεατή παρέχοντάς του μια ολοκληρωμένη εικόνα του παρελθόντος.

The objective of this paper is to present the virtual reality production “Hagia Sophia: 1500 years of History”. It focuses on the creation of 3D historic figures based on various sources and archaeological finds, the reconstruction of the digital model of the Byzantine church in three different chronological periods and the shaping of the entertaining and educational character of the final production. The problems posed during the 3D modelling process along with the selected solutions are discussed, while the technical limitations applicable to a real time production are described with a special emphasis on how these determine the final visual outcome. A brief presentation of the programming aspects of this project follows. The resulting production seeks to embark the viewers on a journey, exposing them to a comprehensive view of the past.

Keywords: Hagia Sophia, Virtual Reality, Reconstruction, 3D Model, Dome, “Tholos”

Introduction

"Hagia Sophia: 1500 years of History" is a Virtual reality production of the Foundation of the Hellenic World (FHW) for the dome theater "Tholos" of the Cultural Center "Hellenic Cosmos", released in December 2015. It has been an ambitious project for a World Heritage monument of paramount cultural and religious importance, comprising of a narrated virtual guided tour, which not only offers information on the building itself, but attempts to provide a comprehensive view on the past.

FHW's mission is the preservation and dissemination of Hellenic culture. Since the late 1990s, its “3D Graphics and Virtual Reality Department” has been using cutting edge technologies to reconstruct the past aiming at different audiences ranging from school visitors to academics. In this paper we will be focusing on:

a) the 3D presentation of historic figures,
b) the 3D reconstruction of the building of Hagia Sophia, and
c) how these are brought together into this entertaining and educational program.

1. Basic concepts

Before describing our work on this project, we must clarify certain definitive aspects concerning the medium we work with and its limitations. These limitations and the ways in which we address them, determine to considerable extent the look and feel of the resulting production.

1.a Virtual Reality

Virtual reality (VR) can be defined as an artificial alternate reality achieved through technical means. The participant in a VR project is immersed in a digital environment with at least two of the five senses, sight and hearing, to achieve suspension of disbelief. Movement and interaction is possible within this environment.

1.b Real Time Graphics

The graphics used to reconstruct virtual worlds for a VR project are called Real Time Graphics. They are most commonly encountered in computer games, and are dependent upon hardware advances. Real Time Graphics are created in such a manner that they can be rendered by computers fast enough to simulate natural uninterrupted motion. However, to facilitate fast rendering, certain restrictions apply.

We use "low polygon meshes", i.e. 3D models of simplified geometry. The size of the respective texture maps has to be small and to abide by the "power of 2" rule with a maximum of 2048 x 2048 pixels. To achieve a sense of realism, we combine diffuse/colour, specular, normal, ambient occlusion and opacity texture maps for our models using shader technology (see Andreadis *et al.* 2010, Wolff 2013). Finally, for animation we use specific types of skeletal "rigging" of the 3D models that are easier to process by the computer and enable specific types of motion. All models created for the Hagia Sophia project, animated or not, were bound by these specifications and restrictions (Fig. 1).

Figure 1 Inauguration of Hagia Sophia in AD 537. A screenshot of the actual VR environment.

1.c The "Tholos" dome theater

The immersion and suspension of disbelief necessary for a successful VR experience of Hagia Sophia is dependent on both hardware and software.

Tholos, the real-time VR Dome Theater of FHW is essentially the VR system where this production is displayed. Tholos utilises a fully digital projection system, configurable in monoscopic, stereoscopic or a mixed mode of operation. It is using 6 pairs of seamlessly blended SXGA+ projectors which display synthesized imagery on a tilted hemispherical reflective surface of 13 m. in diameter (Fig. 2) (Christopoulos *et al.* 2006, Yu *et al.* 2016). The auditorium is designed to host up to 132 visitors at a time and to offer a truly immersive and interactive experience within a virtual world.

This system is operated by a museum educator guide via the combination of a joystick and a manipulator tracker. By developing real-time productions that do not contain pre-rendered content, we provide user interaction for all visitors in order to increase viewer participation. Every visitor seat is equipped with a 2-axis joystick and 4 buttons. During the show visitors are asked to perform actions either competing against each-other (in quizzes for example) or working collaboratively using the joystick to navigate to a specific point (Christopoulos & Gaitatzes 2009).

1.d Interactivity and educational goals

It has been suggested that VR projects should strive to have a successful blend of three components (Kampa *et al.* 2015, Roussou 2006):

- *representation*, i.e. to visualise accurately the reconstructions,
- *experience*, i.e. to present the virtual environment with motivating elements that incorporate knowledge, and
- *interaction*, i.e. to provide the ability to gain insight by actively engaging and even modifying the experience.

Based on these three components we tried to implement the principles of current VR entertainment and game industry practices to provide the educational and entertaining aspect of this project.

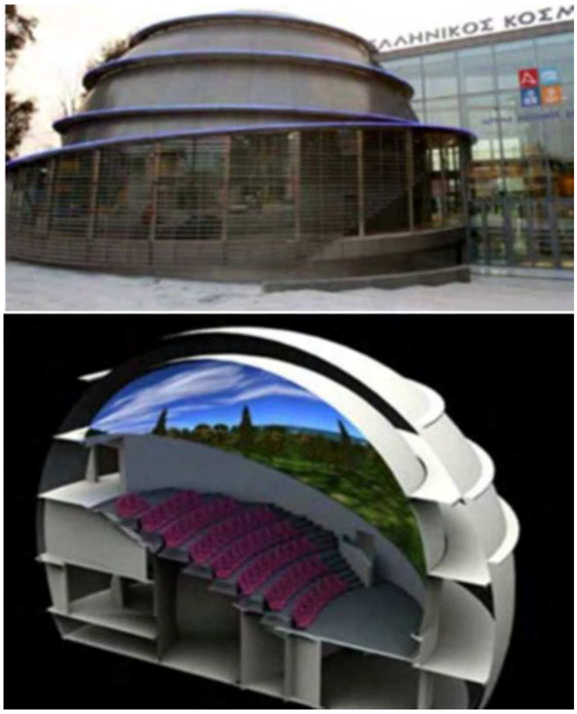

Figure 2 FHW "Tholos" Dome.

It is advocated (Doulamis *et al.* 2011, Schell 2003, Schell *et al.* 2001) that a successful entertainment experience should use the right combination of:

- *interest*, to focus attention,
- *empathy*, to make us feel we are part of the story, and
- *imagination*, to let the visitor fantasize alternate realities.

Storytelling proves to be the best vehicle, as the spectator is compelled to identify with the narrator on an imaginary journey to discover the Hagia Sophia building and its history. A carefully constructed script and the guided tour are intended to capture the visitor's interest with the aid of computer graphics.

Interactivity is considered a cornerstone in creating engagement by building an overlap between perception and imagination that allows for the direct manipulation of the virtual world. Games can take events of low inherent interest and still be compelling, as they make up in psychological proximity. During the experience of the Hagia Sophia 3D walkthrough, the visitors participate in quizzes and can determine what places to visit. The museum educators are also able to ad-hoc initiate interactive quiz and voting procedures with a range of varying questions depending on each user group.

1.e Gamification aspects

Those who believe in using games for education are often motivated by the observation that game players regularly exhibit persistence, risk taking, attention to detail and problem solving skills. Such qualities are deemed ideal for successful learning. Using 3D simulation technology for educational purposes is not a new concept; in the past two decades immersive VR has attracted the attention of many researchers and educators (Lee *et al.* 2008, Roussou & Slater 2005).

However, recent advances in creating videogame applications embedded with effective learning principles (Anderson *et al.* 2009, Leaning 2015) and studies on human computer interfaces for the entertainment industry (Schell *et al.* 2001, Shell 2003) suggest that a combination of successful practices in these areas could provide motivating experiences and strong tools for learning in educational virtual environments.

1.f The role of the human guide

Museum educators are being commonly used as mediators for VR tours. When work started on the Hagia Sophia project we deliberately chose to include the participation of a museum educator as a prerequisite, since it proves to be very beneficial for the educational context.

Recent studies (Economou *et al.* 2008, Pujol *et al.* 2009, Tzortzaki 2001) highlight that the human factor, embodied in the presence of the guide as mediator, remains one of the most crucial factors in terms of educational benefit, entertainment and construction of meaning for visitors. The studies conclude that the majority of visitors prefer to explore the application with a human guide, because it allows direct interpersonal interaction allowing for the museum educator to immediately adapt to the audience and solve doubts or provide more information. In this respect, the experience is regarded to be more vivid and spontaneous compared to passive mediums like movies or planetariums.

2. Production Overview

The Hagia Sophia VR production consists of narrated segments and guided segments. In the former, the viewer experiences a spectacle passively, similar to watching a movie or a documentary. All that is seen and heard is predefined. In the latter, a museum educator takes full control of the navigation and provides freely guided tours through the building. This method allows the museum educator to adapt the tour for varying audiences facilitating a personalised and unique experience. It also enables the visitors to participate through a selection of games. The audience is asked questions and provides answers through the four multi coloured buttons installed on each seat. The narrated segments and guided segments are intertwined to offer a more challenging experience.

The first priority of any educational institution is to maintain its scientific and educational character. A variety of disciplines, ranging from 3D artists and architects to historians, worked together to produce all our 3D assets, historical information and storyline. We made elaborate use of computer game technology and high fidelity Real Time Graphics, trying to keep a unified appearance throughout the entire project. The visual quality was considered crucial for achieving an interesting and compelling experience.

Following extensive historical research and taking under consideration a series of historic events related to the construction and the history of the Hagia Sophia building, work began on forming a script. The objective was to present and underline the spiritual, cultural and political importance of Hagia Sophia, as well as the architectural and decorative characteristics of the actual building.

Although the Hagia Sofia has an extensive 1500 year long history, we choose to reconstruct what are considered the building's most crucial changes both in architecture and decoration, to accommodate a 45 min. dome theatre show. Our historical researchers identified key periods for which we created elaborate 3D models. AD 537: initial construction of the Hagia Sophia, AD 558: renovation and alteration of the dome after a major earthquake, AD 879: creation of important mosaics and organisation of the major ecumenical session that regulated matters between the Catholic and Orthodox Church, AD 1204: sack of

Constantinople with damages to the church by the Crusaders, AD 1261: reconquest of the capital by Michael Paleologos, crowning ceremony in the Hagia Sofia and effort to renovate the building, AD 1346: major earthquake which demolished the dome and parts of the supporting arcs, followed by reconstruction interventions, AD 1453: sack of the city by the Ottomans and conversion of Hagia Sophia to a mosque.

Once the script had been finalised, the necessary 3D models for the production were outlined. In time, historic texts, archeological finds and existing material were translated into our final 3D models. With the addition of animation all 3D assets were gradually brought together into a VR application, which handles all interaction and projected visuals on the “Tholos” dome. Finally, the production was complemented with sound design and music.

3. Building reconstruction

The 3D & VR Department of the FHW has been creating architectural 3D reconstructions for video, printed media, multimedia, web and VR productions since 1997. Most projects involved the reconstruction of buildings and cities from the classical times that exist only in ruins.

The 3D reconstruction of Hagia Sophia presented us with a new challenge. Hagia Sophia has a continuous life of 1500 years. It was built in the 6th century AD as the greatest Christian church of its time and it survived the destructive forces of time, nature and humankind until the present. It has been used as an Orthodox Christian church for a thousand years, as a mosque for another five hundred years and since the 1930’s as a museum and World Heritage monument. Our 3D reconstruction of Hagia Sophia had to stand the comparison with the real building and offer the spectator additional information. As it is intended for the general public, it had to be conclusive for all ages and educational levels. The main difficulty was the size and complexity of the building, as well as the abundance of available information or occasionally the lack of it.

According to the script, we created several 3D models (Fig. 3). These consisted of the interior of Hagia Sophia in three different periods of time, the Justinian (6th century) church with the original and the second dome, plus two more versions of the 9th and 13th centuries. We also constructed models of the exterior of the church in the same three periods. In addition, we made a descriptive animated model of the church showing the design concept and the static problems that the architects had to solve during construction.

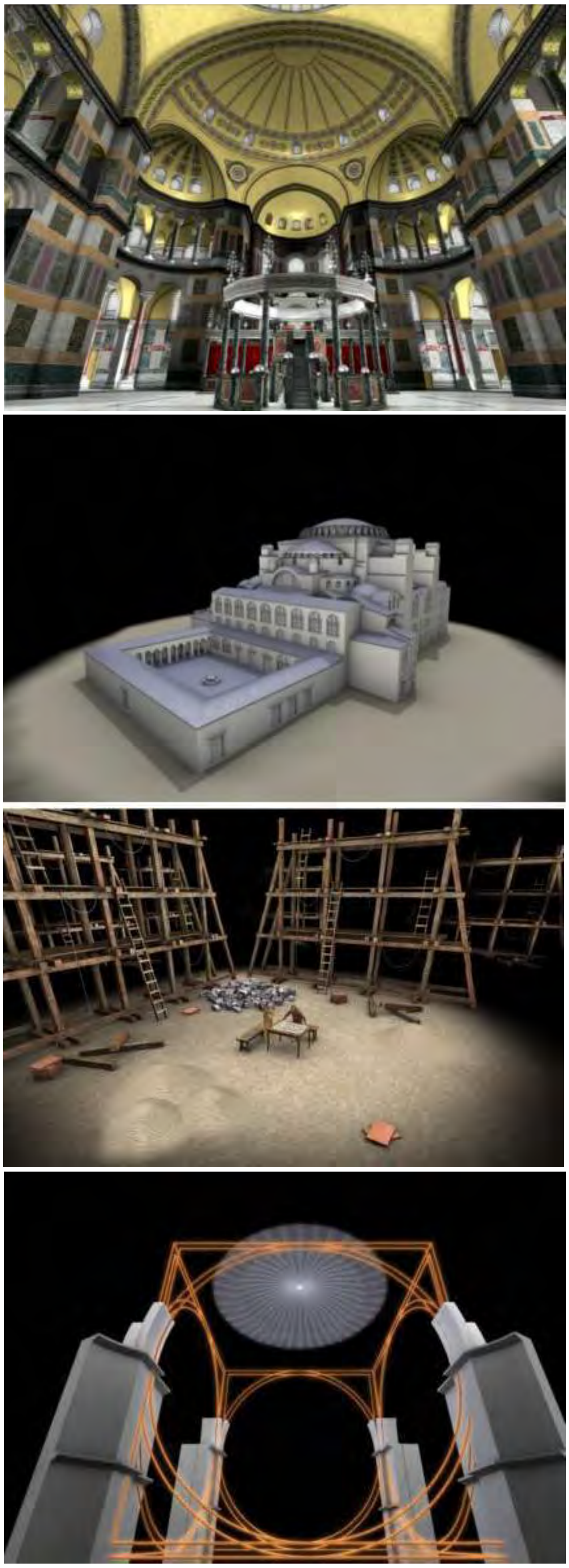

Figure 3 From top to bottom, interior and exterior views of the rendered 3D model and animated visualisations that explain the construction of the building.

Due to the specific needs of the project (VR with low polygon models and low resolution textures) the use of a 3D-scanned dataset for the reconstruction of Hagia Sophia was not a feasible option. Instead we constructed our models from scratch, based on the drawings by Robert Van Nice (1910-1994). Van Nice conducted a large-scale survey of Hagia Sophia from 1937 to 1965 (Van Nice 1963, Van Nice 1964, Van Nice 1965). In 1965, Dumbarton Oaks published the first installment of his drawings in 25 plates. We had in our disposal the augmented edition of 1993, with 46 plates. Prof. Dr. Volker Hoffmann (Bern), one of our consulting experts, having conducted himself a 3D laser scanning of the interior of Hagia Sophia in 2003, was able to confirm the accuracy of these drawings.

Manual reconstruction of a building on the basis of architectural plans and its successive decimation, without losing significant information, can be very difficult and long. This work, however, can produce valid and qualitative reconstructions, provided that the result is examined by experts, as was done in our case. Digital reconstruction of sites or buildings from drawn sources remains a productive approach when 3D laser scans are not available (Tal 2012).

The Van Nice drawings were scanned in high-resolution image files. These digital pictures were imported successively into SketchUp Pro. They were checked for scale divergence in length and width caused by possible expansion or shrinkage of the physical paper plates and they were corrected accordingly and scaled to 1:1. Then they were centered and placed in their proper position in 3D space, thus forming a grid of plans, sections and elevations on which the construction of the 3D models was referenced (Fig. 4).

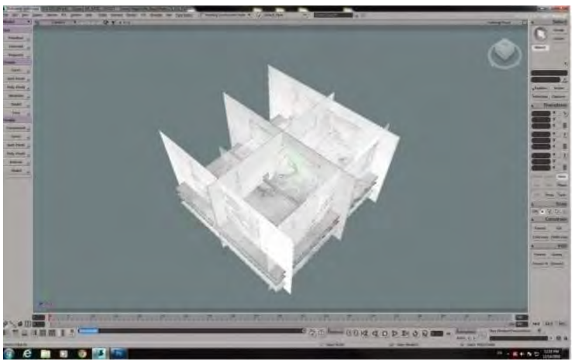

Figure 4 Embedding of the 2D sections and plans in 3D space.

Three modelers worked with this grid. While building the models, the team took care to reproduce as faithfully as possible all variations in size and form of the architectural members of the building, such as the columns and pillars. For the construction of details such as cornices, doorposts, column bases or wall dados etc. detailed vector drawings of their respective profiles were used for extrusions or revolutions.

For the texturing of these models we used three types of maps: diffuse/colour, specular and normal maps to construct a wide variety of materials, such as flat marble surfaces of various colours (e.g. wall panels, floors), marble relief panels, opus sectile panels and decorations, relief decorations, metals (e.g. gold, silver, bronze), non-figurative mosaics and finally figurative mosaics. In addition, ambient occlusion maps were baked on a per scene level. We didn't have the opportunity of taking pictures inside the Hagia Sophia. Therefore, we used every image available from books and the Web as reference for the construction of our textures. We also used all written descriptions on parts of the building now missing, such as the Ambo referenced in the "Description of the Ambo" by Paulus Silentiarius.

We organised a collection of marbles of different colours and we adapted them to the size and specific needs of the project. We took care to allow differences in every texture, so that there is no repetition. For the geometric decorative mosaics, as well as for some opus sectile panels, vector drawings were made and these were then filled with the proper textures (Fig. 5). On all mosaics, as well as on the golden background of the walls and ceilings, specular and normal maps were used to construct the necessary glow, reflection and relief of these surfaces.

Figure 5 A collection of diffuse/colour textures showing decorative mosaics and opus sectile.

The figurative mosaics form a separate category in terms of texturing. Photos and drawings were used as reference for their reconstruction. In the areas where the original figures had been destroyed, we traced the estimated contour of their missing parts and we filled the golden background around them. We consciously refrained from any effort to complete missing figures wherever there was lack of sufficient evidence. The textures used were larger in size compared to other textured features. The "Deesis" mosaic, for instance, is 5.95 m. wide and 4.08 m. tall covering almost an entire wall. In order to capture its unique detail, the resulting maps had to be equally large at 2048 x 2048 pixels. To present the actual look and feel of such mosaics we created sets of colour, specular and normal maps.

3. Character Reconstruction

The reconstruction of historic characters and costumes is most commonly and traditionally encountered in the form of illustrations. However, in recent years re-enactments and forensic facial reconstruction, both material and digital, have often offered stunning results. Although the above have been a major source of inspiration, our approach to the reconstruction and presentation of digital historic figures for a VR project was dictated by the very nature of this medium. This meant that the amount of detail present in our final models had to be supported by three 1024 x 1024 pixel textures and 3000 to 4000 triangle geometries. We could not afford for computationally demanding cloth simulations, animation rigs, or complex shaders, which are otherwise used in 3D computer graphics.

Overall, a total of 22 historic figures were created for the different scenes, excluding the crowd visible at the coronation ceremony of emperor Michael VIII Palaiologos in 1261. These 22 characters cover a wide spectrum from sixth century laymen (Makri 2009) to thirteenth century clergymen and Varangian Guardsmen (D' Amato & Rava 2010). At the same time, the available information on these characters varied greatly from the case of the emperor Justinian who was one of the best documented characters to that of the unnamed thirteenth century deacons.

The process of recreating a real time digital character started from an illustration. Wherever possible this illustration would be contemporary or near contemporary to the intended date of depiction. Otherwise a modern or more recent interpretation would be used. A careful study of relevant texts from a variety of sources (see Heath *et al.* 1995, Kalamara *et al.* 2001, Parani 2003) in combination with archeological finds were used to help understand and supplement what the illustrations depicted.

Creating 3D models on a 1:1 scale requires accurate information which is far from present in the often stylised Byzantine illuminations. Although modern illustrations of Byzantines are often more detailed, their accuracy is subject to the interpretation of the original sources. In addition, archeological finds related to clothing and accessories from this period usually only offer a fragmentary impression of the original artefacts. Furthermore, certain types of similar garment that are still in use today were made differently in the 9th and 13th centuries, both in terms of design and materials (e.g. the *epitrachilion* worn by bishops).

Once the available information started to make sense the 3D modelling process begun. It was a creative dialogue similar to putting together a puzzle with several missing pieces, often tracing our steps backwards as the 3D model was gradually being formed. Notes were kept on all types of different aspects for each character, such as age, height, hair colour and style, skin complexion, eye colour, possible type of garment, garment decorations, fabric colours, possible decoration combinations, shoes, boots, accessories, belts, buckles, arms, and so much more, depending on what information was available.

During this process questions emerged almost on all aspects of recreating the clothes and heads of characters. These were addressed by trying different interpretations and selecting the ones that offered more credible visual results. In the case of the emperor Michael VIII and augusta Theodora we experimented with the size of the gems borne on their clothes and crowns, the width of their imperial "Sakoi" or the reconstruction of the "Vaio" held by Theodora based on the 14th century illumination of Anne of Savoy and a contemporary description (Verpeaux 1966).

The first step was to define gender and body type. From these, a base 3D model was created, which was clothed in high resolution garments. Clothing was a particularly dialectic process as the final result had to satisfy both the nearest illustration and the textual and archeological information gathered on each character. The definition of cloth templates and seams was particularly challenging, as their simulation on the base model was computationally very demanding and unpredictable. The templates and folds often had to be reworked, while on occasions the initial interpretation of how the cloth would have been sewn was not successful. In the case of the *metropolitans* for instance, the original designs were considerably altered, when revisited a year later to better match 9th and 13th-14th century depictions. The cloths of the patriarchs were also the most complex to achieve, as four main layers of cloth fell on top of each other: *omoforion*, *failonion*, *epitrachilion* and *stoicharion* and their simulations had to be dealt with repeatedly, in successive order (see Fig. 6).

Once the high resolution cloth models were made, they had to be textured. During this process additional detail was added, including colours, patterns, additional creases, and fabric texture. This was made possible with the use of colour and specular map textures and on occasion with detailed normal maps to enhance the final appearance of the cloth.

Figure 6 Patriarch Photius: high resolution model left (529,726 triangles) and low resolution model right (3,565 triangles). Notice the successive layers of garments.

Afterwards, a low resolution model, appropriate for use in the VR program, was produced, on which diffuse, normal, and specular maps were *baked* from the high resolution one, using projection mapping (Petinneo 2015) (Fig. 6).

Work on the head and hands followed. The hands contained small variations from one character to the other, mainly in size and skin colour. In the case of the heads, work began with the low resolution geometry shaped into place according to what we knew of each character. The head was mapped with a colour map and a more detailed version would be sculpted in 3D, from which normal maps were extracted. Finally, a specular map would be created based on the colour map.

One of the bigger challenges was the creation of realistic long beards particularly for the 13th century characters. A multitude of beard photographs were used for their composition, while special attention was paid to the creation of detailed opacity maps to describe stranded hair and the geometry on which these were mapped. The final style had to match that seen on 13th and 14th century wall paintings and manuscript illuminations (Fig. 7). Out of all the characters, the emperor Justinian was the one with most sources on his appearance. Descriptions of him survive along with certain contemporary depictions, most notably the mosaic at the Basilica of San Vitale in Ravenna. Yet the information available was still hardly enough for the degree of detail required, so features like pores, wrinkles and muscle details were added to provide a realistic rendering. In the case of Anthemius of Tralles and Isidore of Miletus we could infer their age, guess their hairstyles from contemporary illustrations and attribute skin and eye colours common to Mediterranean peoples (Fig. 8). Finally, another interesting example was the head of Patriarch Photius. Its design was influenced by key features common in religious icons depicting him, such as white hair and beard, black brows, strong cheekbones, big forehead etc. (see Fig. 6). Overall, the head models were worked rather freely, especially in the details, but always with respect to surviving information.

Figure 7 Coronation of emperor Michael VIII Palaiologos.

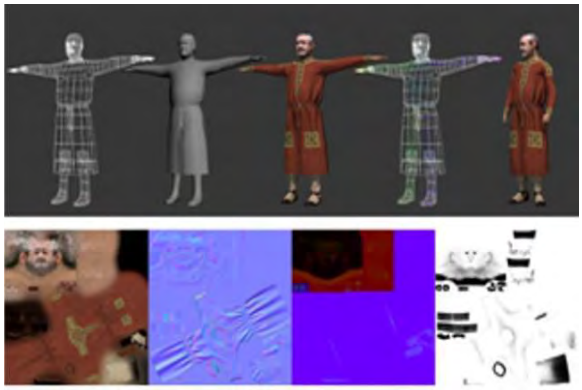

Figure 8 Top to bottom, various states for the model of Isidore of Miletus and the respective diffuse/colour normal, specular and ambient occlusion texture maps.

With the completion of the low resolution body and head, the character was ready for "rigging". A skeletal system of bones was created for the movement of both the character's joints and clothes. During this process, the topology of each bone and its associations with all other neighboring bones was defined, while the 3D geometry was bound onto this skeleton on a per vertex level to deform accordingly (Andreadis *et al.* 2010). The characters were animated, using motion capture clips and key frame animation for primary motion and rigid body simulation for secondary motion - as was the case of Justinian's cloak and *perpendulia*. Justinian was perhaps the most difficult character to animate with the most complex skeletal system (i.e. rig). During the coronation scene of emperor Michael VIII, where the church had to be filled with a crowd, the use of animation was avoided as the frame rate (number of frames displayed per second) was dropping and any motion would become randomly fragmented and therefore, very distracting. The characters were posed instead into place with the use of a rig, while the geometry of the resulting models was modified to appear more natural (Fig. 7). Finally, all models were exported into the appropriate 3D format for integration into our engine.

2.b Creating the Crowd

Filling the church of Hagia Sophia with a crowd for the coronation of emperor Michael VIII, without the engine slowing down almost to a halt, was the final challenging task of the project, as far as character rendering was concerned (Thalmann *et al.* 2013). Creating an effective system for rendering moving crowds is a particularly demanding task. Since, however, the crowds in our case had limited movement inside the church, we deployed an older method based on image based rendering techniques (Pleines 2008). A set of ten characters were derived from those already present in the scene, to limit the use of extra textures. They were all given a new colour map with two sets of garments and thus twenty different model variations were obtained. Then, each model was posed at a different stance creating even more variations, until a group of 132 different characters was reached. The church was populated based on this group.

While populating the church, it was possible to verify that it could actually be filled with approximately 25,000 people (Dewing 1961). The most elaborate aspect of this endeavor was polygon reduction, i.e. the process of reducing the amount of geometrical complexity and detail for the VR program to run smoothly. From an initial “polygon count” of approximately 1.5 million triangles it was possible to reduce the geometry down to less than 370.000 triangles. This was achieved:
- by eliminating all characters not visible to the camera,
- by creating front and side planes, texturally presenting the characters who stood at a distance, and
- by reducing the geometry on the remaining 3D characters into several levels of detail, depending on their proximity to the camera and the camera’s viewing angles.

4. The technology behind the “Hagia Sophia” project.

To drive a multi-display environment, such as a dome, multiple graphics outputs have to be synchronised at each frame to generate partial views of the same panorama.

4.a Software

The VR software used in the Hagia Sophia project was the in-house developed Enhanced Visualisation System (EVS). EVS supports cluster rendering through a custom protocol that was developed and designed specifically for the synchronisation of multiple cluster units, consisting of a central unit (master) and multiple subunits (slaves) (Gaitatzes *et al.* 2006). Each unit is a completely self contained VR system, advancing at each frame according to user and application dependent variables. This set of data is however limited and consists only of user interaction primitive actions (e.g. button presses, tracker input, joystick values) and a global application reference clock. The master unit synchronises the slaves using special synch packets and provides a highly parallel execution that has almost zero scaling overhead (frame lag) when adding new slave units/nodes. In this manner, a consistent construction of the virtual world from multiple viewpoints and on multiple screens is made possible.

EVS supports multi-channel setups, allowing monoscopic, passive stereo, active stereo or left/right individual eye operation through a custom developed display library that handles arbitrary display surfaces and viewing modes. In this manner an application can be configured to run on a variety of VR systems such as CAVE, Reality Center, Dome, Powerwall as well as on single screen desktop monitors and HMDs. Different setups are easily configured through a simple and effective XML script allowing multiple configurations to be present in a single file and share some common features if necessary (Andreadis *et al.* 2010).

Our engine is script based, meaning that ASCII script files describe the virtual world and user interactions. EVS also allows the programming of dynamic interaction and events utilising the Lua programming language. The actual rendering module was developed on top of OpenSceneGraph (Rui 2012). It is written in C++ and uses OpenGL for cross-platform graphics rendering. (Fig. 9) shows the architecture of the entire environment, developed on a Linux operating system.

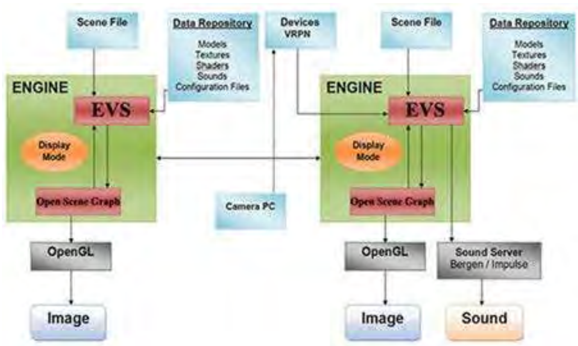

Figure 9 The EVS architecture.

4.b Shaders

To bring this virtual world into existence lighting and shading calculations were performed through programmable shaders. EVS provides a Shading Language called ESL (Enhanced Shading Language). ESL is an enhanced version of the OpenGL Shading Language GLSL. (Andreadis *et al.* 2010).

In the Hagia Sophia project different shaders have been used to present more accurately and convincingly a variety of surfaces (e.g. human skin, marble slabs, golden mosaics, silk and linen clothes, metals) as well as geometries (e.g. marble reliefs, mosaic tiles, opus sectile, belt buckles, cloth creases, human wrinkles) (Fig. 10).

Figure 10 The Nave: view to the west and Basileios Gate, displaying a multitude of shaders.

Conclusion

All the way from sources to reconstructed 3D we tested different possibilities providing a new vantage point for further research. Despite the difficulties encountered when combining different sources and the technical limitations of the medium we work with, we were able to deliver an enhanced visual experience, an educational and entertaining glimpse to the past.

Acknowledgments

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ΔΙΑΔΙΚΤΥΑΚΕΣ ΕΦΑΡΜΟΓΕΣ ΓΙΑ ΤΟ ΝΕΑΝΙΚΟ ΚΟΙΝΟ. ΕΝΑ ΠΑΡΑΔΕΙΓΜΑ ΤΟΥ E-ΒΥΖΑΝΤΙΝΟΥ ΚΑΙ ΧΡΙΣΤΙΑΝΙΚΟΥ ΜΟΥΣΕΙΟΥ

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Περίληψη/Abstract

Διανύουμε τη δεύτερη δεκαετία του 21ου αιώνα και η συζήτηση για τον ρόλο που παίζουν οι νέες τεχνολογίες στην εκπαιδευτική διαδικασία είναι ιδιαίτερα επίκαιρη. Μεγάλα δημόσια μουσεία διαθέτουν ανεξάρτητες ιστοσελίδες που έχουν, κυρίως, ενημερωτικό χαρακτήρα για τις δράσεις τους. Σε κάποια μουσεία υπάρχουν ήδη εκπαιδευτικές εφαρμογές που στοχεύουν στο νεανικό κοινό. Το Βυζαντινό και Χριστιανικό Μουσείο προχώρησε δυναμικά, το 2015, στην κατασκευή μιας ψηφιακής πλατφόρμας με σκοπό να επικοινωνήσει με ποικίλες κατηγορίες κοινού. Σε αυτό το πλαίσιο, το Μουσείο σχεδίασε και κατασκεύασε σειρά εκπαιδευτικών εφαρμογών που ακολουθούν τα συνήθη πρότυπα, σχετικά νέα για τα δεδομένα των μουσείων. Με αφετηρία τη μόνιμη έκθεση αξιοποιούνται εκθέματα με σκοπό αφενός να κεντρίσουν ευχάριστα το ενδιαφέρον των νεαρών χρηστών και να εμπλουτίσουν τις γνώσεις τους κι αφετέρου να ενθαρρύνουν μια κριτική ματιά απέναντι στα αντικείμενα. Μέσα από τον παιγνιώδη τρόπο διαδικτυακής επίσκεψης ίσως δημιουργηθεί και η ανάγκη μιας μουσειακής εμπειρίας σε πραγματικό χρόνο και τόπο.

In the second decade of the 21st century, the discussion on the role of new technologies in the educational process is quite timely. Big state museums have their own web pages, providing mostly information on their activities. Some museums offer also online educational applications, aiming at attracting young audiences. In 2015, the Byzantine and Christian Museum launched a digital platform intended to engage various audience categories. In this framework, the Museum designed and implemented a series of educational applications, based on well-tried practices, which are, however, relatively new to the Greek museums reality. Elements of the permanent exhibition are used in ways that intrigue young users, giving them a chance to enhance their knowledge as well as to grow a critical attitude towards museum objects. Thus, the playful context of the online visit may give rise to an urge for experiencing a museum visit in real life.

Λέξεις Κλειδιά: Βυζαντινό και Χριστιανικό Μουσείο, Εικονικό Μουσείο, Εκπαιδευτικές Εφαρμογές, Παιχνίδι Μνήμης, Παζλ, Αινίγματα

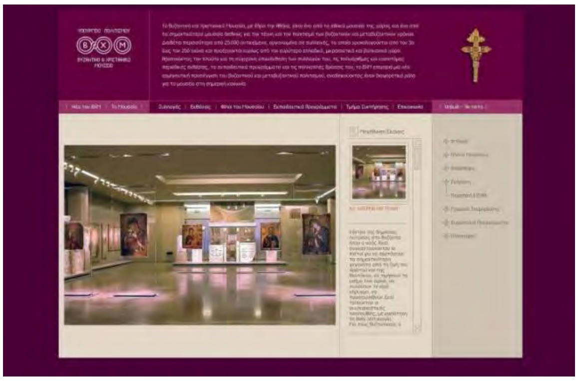
Εισαγωγή

Διανύουμε ήδη το τέλος της δεύτερης δεκαετίας του 21ου αιώνα. Η χρήση των νέων τεχνολογιών πληροφορίας και επικοινωνίας στην καθημερινότητά μας είναι πια δεδομένη και αναγκαία. Φυσικό κι επόμενο ήταν οι πολιτιστικοί-εκπαιδευτικοί οργανισμοί, όπως είναι τα μουσεία, να ακολουθήσουν τα κελεύσματα της εποχής. Συγκεκριμένα, τα μεγάλα ελληνικά δημόσια Μουσεία έχουν ξεκινήσει μια προσπάθεια να δώσουν το στίγμα τους στο χώρο των ψηφιακών εφαρμογών, τόσο σε θέματα τεκμηρίωσης συλλογών όσο και σε θέματα προβολής και επικοινωνίας. Η ανάπτυξη πληροφοριακών συστημάτων για κρατήσεις θέσεων, πώληση εισιτηρίων, ηλεκτρονικό έλεγχο ασφαλείας, διαδικτυακή πώληση προϊόντων είναι από τις βασικές ανάγκες που χρειάζεται να καλυφθούν. Εκτός αυτών, οι νέες τεχνολογίες δίνουν λύσεις για παροχή πληροφόρησης και μάθησης μέσω φιλικών εφαρμογών, όπου κύρια επιδίωξη είναι ο χρήστης να βρεθεί σε συνθήκες διάδρασης.

Στο Βυζαντινό και Χριστιανικό Μουσείο (ΒΧΜ), η εντατική προσπάθεια σχεδιασμού και οργάνωσης ανοιχτών διαύλων επικοινωνίας με την κοινωνία ξεκινά από το 2000. Ένα από τα οράματα του τότε διευθυντή του Μουσείου, του αείμνηστου Δημήτρη Κωνστάντιου, ήταν το Μουσείο να αποτελέσει σημείο αναφοράς για τα πολιτιστικά δρώμενα και να δημιουργηθεί η αίσθηση ενός οικείου χώρου. Να εντυπωθεί στη συνείδηση των περισσοτέρων ότι το ΒΧΜ είναι το «Μουσείο Μας».

1. Η προηγούμενη κατάσταση

Η διαδικτυακή προβολή του ΒΧΜ εξυπηρετούνταν από τον κόμβο ΟΔΥΣΣΕΑΣ του Υπουργείου Πολιτισμού και Αθλητισμού (ΥΠΠΟΑ) με πολύ περιορισμένες δυνατότητες, τόσο ως προς την αρχιτεκτονική του όσο και ως προς τη δυνατότητα ανάπτυξης διαδραστικών εφαρμογών (http://odysseus.culture.gr/h/1/gh151.jsp?obj_id=3349, επίσκεψη 19/06/2017).



Εικόνα 1 Η πρώτη επίσημη ιστοσελίδα του Βυζαντινού & Χριστιανικού Μουσείου.

Σήμερα, καταβάλλονται προσπάθειες από την αρμόδια υπηρεσία του Υπουργείου Πολιτισμού και Αθλητισμού για αναβάθμιση του κόμβου. Η ανάγκη να προβάλλονται σχεδόν σε καθημερινή βάση οι δράσεις, οι εκθέσεις (μόνιμη και περιοδικές) καθώς και οι συλλογές, οδήγησε αναπόφευκτα, το 2004 (χρονιά εγκαινίων του πρώτου μέρους της μόνιμης έκθεσης), στον σχεδιασμό μιας ανεξάρτητης ιστοσελίδας του ΒΧΜ, στην οποία -για πρώτη φορά- το ίδιο το Μουσείο είχε τη μερική διαχείριση του περιεχομένου (Βοσνίδης 2008, 98-99). Η σελίδα ήταν σχεδιασμένη σε flash, χωρίς ενιαίο σύστημα διαχείρισης (Εικ. 1). Έτσι, αν και αισθητικά ήταν ικανοποιητική, πρακτικά δημιουργούσε ποικίλα προβλήματα, όπως αυτό της ανανέωσης του περιεχομένου, γεγονός που αντιμετωπίστηκε με εμβαλωματικές προσθήκες και βελτιώσεις.

2. Η νέα ιστοσελίδα

Οι αυξημένες επικοινωνιακές ανάγκες, οι δυσκολίες στη διαχείριση του περιεχομένου και η επιθυμία για ανανέωση στην αισθητική της ιστοσελίδας δημιούργησαν τις προϋποθέσεις για τον σχεδιασμό μιας νέας (Εικ. 2, Βοσνίδης 2011, 104-107). Με δεδομένη την προηγούμενη εμπειρία, τέθηκε ως προαπαιτούμενο η δημιουργία ενός πολύ εύχρηστου συστήματος διαχείρισης σε όλα, σχεδόν, τα επίπεδα λειτουργίας της ιστοσελίδας. Η διάρθρωση (site map) της προηγούμενης κρατήθηκε, με λίγες βελτιώσεις. Στόχος ήταν η προβολή της μόνιμης έκθεσης (το πρώτο μέρος με εκθέματα από τον 5^{ο} έως 15^{ο} αιώνα εγκαινιάστηκε το 2004, το δεύτερο μέρος με εκθέματα από τον 16^{ο} έως τον 19^{ο} αιώνα εγκαινιάστηκε το 2010). Έτσι, δόθηκε μεγαλύτερη έμφαση σε αυτό το πεδίο: πληθώρα εκθεμάτων, πλούσιο φωτογραφικό υλικό και απλά συνοδευτικά κείμενα.

Από το 2010 μέχρι σήμερα, το ΒΧΜ υπάρχει και επικοινωνεί ψηφιακά μέσω αυτής της ιστοσελίδας, ενώ έχει επεκταθεί και στα μέσα κοινωνικής δικτύωσης (Facebook και Twitter, κανάλι YouTube), τα οποία τροφοδοτούνται, ως επί το πλείστον, από την επίσημη ιστοσελίδα.

Εικόνα 2 Η παρούσα επίσημη ιστοσελίδα του Βυζαντινού & Χριστιανικού Μουσείου (http://byzantinemuseum.gr/, επίσκεψη 20/9/2017).

Στη διάρκεια των χρόνων της λειτουργίας της, η ιστοσελίδα του Μουσείου έχει αντιμετωπιστεί κυρίως ως εφαρμογή που συμπληρώνει την επικοινωνία του σε ό,τι αφορά τις διάφορες δράσεις του. Πρόκειται για μια προσέγγιση που είναι διάχυτη σε πολλές υπηρεσίες του Υπουργείου Πολιτισμού. Έτσι, ενώ από τη μία οι τεχνολογικές εξελίξεις προχωρούν σε ό,τι αφορά τον λεγόμενο «εκδημοκρατισμό της γνώσης» και το «συμμετοχικό μουσείο», από την άλλη παρατηρείται δυσπραγία και υποτίμηση του ρόλου που μπορεί να παίξει το διαδίκτυο προς αυτή την κατεύθυνση.

Μια από τις βασικές αιτίες είναι η έλλειψη πιστώσεων για την τακτική, λελογισμένη αναβάθμιση των υποδομών (είτε αφορά σε επίπεδο αρχιτεκτονικής και προγραμματισμού είτε αφορά σε επίπεδο υλικοτεχνικού εξοπλισμού). Η αναζήτηση πόρων για την κάλυψη τέτοιων δαπανών είναι ιδιαίτερα δύσκολη, ειδικά στη συγκεκριμένη συγκυρία.

3. Το Βυζαντινό και Χριστιανικό Εικονικό Μουσείο

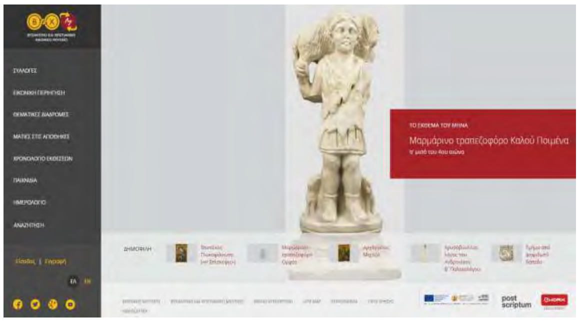
Έτσι, το Επιχειρησιακό Πρόγραμμα «Ψηφιακή Σύγκλιση» (Ειδικός Στόχος 2.1. «Βελτίωση της καθημερινής ζωής μέσω ΤΠΕ – Ισότιμη συμμετοχή των πολιτών στην Ψηφιακή Ελλάδα» του Άξονα Προτεραιότητας 2 «ΤΠΕ και Βελτίωση της Ποιότητας Ζωής») έδωσε την ευκαιρία στο ΒΧΜ, το 2012, να προχωρήσει στον σχεδιασμό μιας πλατφόρμας, με την προσδοκία να περάσει πια στην «εποχή της διάδρασης». Το ύψος του προϋπολογισμού ανερχόταν στα 205,000 ευρώ.

Το έργο πραγματοποιήθηκε με τη διαδικασία της αυτεπιστασίας, γεγονός πολύ σημαντικό αφού επέτρεψε στο ίδιο το μουσείο να παρακολουθεί, στενά και σε βάθος κάθε βήμα του. Αντικείμενο του έργου ήταν η συνολική ψηφιακή διαχείριση των συλλογών και των λειτουργιών του ΒΧΜ και η ανάπτυξη διαδραστικών πολιτιστικών εφαρμογών για τη διαδικτυακή πρόσβαση στις συλλογές του πολλών και διαφορετικών ομάδων κοινού σε εθνικό και διεθνές επίπεδο: γενικού κοινού και κοινού με ειδικά ενδιαφέροντα. Ένα πολύ μεγάλο έργο που είχε ήδη γίνει τα προηγούμενα χρόνια, ήταν η ψηφιοποίηση του 80 % των συλλογών του Μουσείου. Το ΒΧΜ εξακολουθούσε να αναζητεί νέους τρόπους συγκροτημένης προβολής των συλλογών του και παράλληλα να προχωρήσει στην αναβάθμιση των υπηρεσιών του προς τους επισκέπτες.

Το *Βυζαντινό και Χριστιανικό Εικονικό Μουσείο* τέθηκε σε λειτουργία το καλοκαίρι του 2015 (Εικ. 3). Η φιλοσοφία της νέας ψηφιακής πλατφόρμας είναι να υπάρχουν όσο το δυνατόν περισσότερες διασυνδέσεις μεταξύ των επιμέρους ενοτήτων και εφαρμογών, διαμέσου των αντικειμένων συλλογών Στην εικονική περιήγηση ο χρήστης έχει τη δυνατότητα να περιηγηθεί σχεδόν το σύνολο της μόνιμης έκθεσης και να περιεργαστεί συγκεκριμένα σημεία ενδιαφέροντος όπου παρέχονται αρκετές πληροφορίες.

Περιλαμβάνει πολυμεσικές, διαδικτυακές, δια-δραστικές εφαρμογές, που ενημερώνουν και εκπαιδεύουν, ψυχαγωγώντας τους επισκέπτες, σύμφωνα με την αρχή της ψυχαγωγικής μάθησης (edutainment). Τώρα πια, προτείνεται μια περιήγηση στη μόνιμη έκθεση με εναλλακτικό τρόπο, διαφορετικό από τους μέχρι τώρα γνωστούς για το ΒΧΜ. Ο επισκέπτης «τριγυρνά» ανάμεσα σε ψηφιακά εκθέματα, έχοντας επιπλέον τη δυνατότητα να ανασύρει πληροφορίες και να δημιουργήσει τη δική του αφήγηση. Οι πληροφορίες που προκύπτουν από τις δικές του επιλογές μπορούν να συνδεθούν ψηφιακά με άλλα αντικείμενα της μόνιμης έκθεσης, ή ακόμη και με αντικείμενα που φυλάσσονται στις αποθήκες του Μουσείου.

Έτσι, το Μουσείο, για πρώτη φορά, προσφέρει στον ψηφιακό επισκέπτη το προνόμιο της θέασης και απόλαυσης αντικειμένων των οποίων η φυσική παρουσία είναι, για διάφορους λόγους, αποκλεισμένη από τον «πραγματικό» χώρο του Μουσείου. Οι ψηφίδες των πληροφοριών που επιλέγει ο χρήστης συνθέτουν το μωσαϊκό της ιστορίας των ανθρώπων και της κοινωνίας τη συγκεκριμένη στιγμή που παρήγαγαν τα συγκεκριμένα αντικείμενα, ένα μωσαϊκό, όμως, διαρκώς –ως έναν βαθμό– μεταβαλλόμενο, αφού συνδιαμορφώνεται ανάλογα με τις εκάστοτε επιλογές που κάνει κάθε επισκέπτης μεταξύ των προεπιλογών των επιμελητών.



Εικόνα 3 Από την αρχική σελίδα του Βυζαντινού & Χριστιανικού Εικονικού Μουσείου (http://www.ebyzantinemuseum.gr, επίσκεψη 21/9/ 2017).

4. Οι εκπαιδευτικές εφαρμογές

Οι ψηφιακές εκπαιδευτικές εφαρμογές εντάχθηκαν ως υποέργο στην κατασκευή του Εικονικού Μουσείου και έτσι, για πρώτη φορά, δόθηκε η δυνατότητα διάδρασης με το νεανικό κοινό στο Διαδίκτυο. Είναι κοινώς αποδεκτό ότι το ενδιαφέρον των νέων (και ειδικότερα των παιδιών) έχει οδηγήσει τους παιδαγωγούς και άλλους επαγγελματίες του χώρου να διερευνήσουν και να δοκιμάσουν τη χρήση των ηλεκτρονικών παιχνιδιών ως εκπαιδευτικών εργαλείων (Gee 2003). Οι εκπαιδευτικές εφαρμογές του Εικονικού Μουσείου, διαθέσιμες πια στο διαδίκτυο, δεν διεκδικούν δάφνες τεχνολογικής ή μουσειοπαιδαγωγικής καινοτομίας. Η συζήτηση για την αξιοποίηση της ψηφιακής τεχνολογίας στην επικοινωνία με το νεανικό κοινό έχει ξεκινήσει εδώ και τρεις δεκαετίες, με πολύ ενδιαφέρουσες απόψεις και προτάσεις και άφθονες εφαρμογές διεθνώς.

Στην περίπτωση του ΒΧΜ, ακολουθήσαμε τις βασικές αρχές της ψηφιακής διαμεσολάβησης, εφαρμόζοντας δοκιμασμένες και ασφαλείς πρακτικές, προκειμένου, με αυτή την αφετηριακή δράση, να διαμορφώσουμε ένα στέρεο πλαίσιο ψηφιακής «οικειότητας» και ανεπιτήδευτης επικοινωνίας, μακριά από άκαιρους φαραωνισμούς και εξεζητημένες ή επιδεικτικές λύσεις, με τις τυχόν συνεπαγόμενες δυσκολίες στη συντήρηση και υποστήριξή τους. Εξαρχής, η προσπάθεια ήταν να ενσωματώσουμε τις πληροφορίες για τα επιλεγμένα αντικείμενα - εκθέματα που περιλαμβάνουν οι ψηφιακές εφαρμογές σε τύπους δραστηριοτήτων που θα ενθαρρύνουν τους χρήστες να μελετήσουν το αντικείμενο ή να αναζητήσουν περισσότερα στοιχεία. Για τα εκπαιδευτικά παιχνίδια θέσαμε ως βασική αρχή να ακολουθούν μια δομημένη διαδρομή και να βασίζονται σε κανόνες που δεν μεταβάλλονται (Burn & Carr 2006, 17). Τα συμβατικά παιχνίδια επανασχεδιάστηκαν για το ψηφιακό περιβάλλον και συνδέθηκαν ευθέως με τα αντικείμενα των συλλογών, με σκοπό όχι μόνο να προσφέρουν γνωστικό περιεχόμενο αλλά και να αναδείξουν το ιδιαίτερο περιεχόμενο και τον χαρακτήρα του ΒΧΜ.

Έχει διατυπωθεί η άποψη ότι η ενασχόληση με τέτοια παιχνίδια επιτυγχάνει την πλήρη εμβύθιση και τη συνεχιζόμενη κινητοποίηση για επίτευξη μεγαλύτερων σκορ και απόκτηση ικανοτήτων, ενεργοποίηση της φαντασίας και της κριτικής σκέψης, και ανάπτυξη ικανοτήτων λήψης αποφάσεων (Amory *et al.* 1999, 312-313), τα οποία είναι στο σύνολό τους απαραίτητα προκειμένου να εξελιχθεί το παιχνίδι. Κατά τον σχεδιασμό των εκπαιδευτικών εφαρμογών έγινε προσπάθεια να αξιοποιήσουμε το τρίπτυχο φαντασία, περιέργεια και πρόκληση, με σκοπό τα παιχνίδια να είναι ευχάριστα και να κρατούν το ενδιαφέρον των χρηστών (Malone, 1981).

Εικόνα 4 Η εκπαιδευτική εφαρμογή «Ταίριαξε τις εικόνες».

Η πρώτη εφαρμογή τιτλοφορείται **«Ταίριαξε τις εικόνες»** και είναι ένα παιχνίδι μνήμης (Εικ. 4). Διαθέτει τρία επίπεδα δυσκολίας: εύκολο (4 κάρτες), μέτριο (8 κάρτες) και δύσκολο (12 κάρτες). Τα παιχνίδια μνήμης τέτοιου τύπου είναι πολύ συνηθισμένα και χρησιμοποιούνται συχνά σε όλα τα μαθησιακά περιβάλλοντα. Κάθε κάρτα αντιστοιχεί σε ένα από τα εκθέματα της μόνιμης έκθεσης. Ο παίκτης είναι απαραίτητο να ταιριάξει σωστά όλα τα ζευγάρια. Έτσι, αυτή η εφαρμογή μπορεί να γίνει χρήσιμο εργαλείο για τον εκπαιδευτικό ή τον γονιό. Βοηθάει τον χρήστη να αναπτύξει τις μνημονικές του λειτουργίες και να ανακαλύψει τις σχέσεις που υπάρχουν ανάμεσα στα αντικείμενα και τη μόνιμη έκθεση. Σε κάθε σωστό ταίριασμα εμφανίζονται πληροφορίες για το αντικείμενο. Για να είναι πλήρης, εύληπτη και συνάμα ελκυστική, η πληροφορία δομείται με τον εξής τρόπο:

α) φωτογραφία,
β) στοιχεία για τον χρόνο κατασκευής και τη χρήση,
γ) ένα «μυστικό», δηλαδή, μια επιπλέον, ειδικότερη, πληροφορία, που μπορεί να σχετίζεται με τη χρήση, το υλικό, τον τρόπο απόκτησης κ.λπ.

Με τον τρόπο αυτό, υποδηλώνεται ταυτόχρονα η πολυσημία, η δυνατότητα για πολλαπλές αναγνώσεις κάθε αντικειμένου. Το επίπεδο δυσκολίας του παιχνιδιού δεν καθορίζεται μόνο από τον αριθμό των καρτών. Στο τρίτο και δυσκολότερο επίπεδο, οι εικόνες δείχνουν λεπτομέρειες και όχι ολόκληρο το αντικείμενο. Σκοπός είναι να κεντριστεί έτσι η περιέργεια του παίκτη για περαιτέρω διερεύνηση και ανακάλυψη.

Εικόνα 5 Η εκπαιδευτική εφαρμογή «Με δικά σας χρώματα».

Συνοψίζοντας, η εν λόγω εφαρμογή στοχεύει τόσο στην ανάπτυξη των δεξιοτήτων του νεαρού παίκτη όσο και στην ανάδειξη της ποικιλίας των εκθεμάτων και του ρόλου τους στη μόνιμη έκθεση.

Η επόμενη εφαρμογή έχει τον τίτλο **«Κολλάω, χρωματίζω, μαντεύω»**. Πρόκειται για τρία αυτοτελή παιχνίδια: α) *Με τα δικά σας χρώματα*, β) *Τι είμαι;* και γ) *Συναρμολογούμε τα σπασμένα αντικείμενα*.

α) Το παιχνίδι *Με τα δικά σας χρώματα* (εικ. 5) είναι καθοδηγημένη μορφή εφαρμογών ζωγραφικής. Ο χρήστης επιλέγει έναν από τρεις διαφορετικούς «καμβάδες» και τον χρωματίζει με τα χρώματα της δικής του προτίμησης. Για παράδειγμα, σε ένα ψηφιδωτό του 5ου αι., η εικονιζόμενη άμπελος μπορεί να έχει κίτρινο βλαστό και κόκκινα σταφύλια, σε ένα φύλλο χαρτιού του 18ου αι. τα σπίτια του χωριού Τσερκουβίτσα αποκτούν γαλάζια κεραμίδια. Η εφαρμογή έχει σκοπό να δώσει τη δυνατότητα στον χρήστη να υπερβεί τη θέση του παρατηρητή/θεατή του μουσειακού αντικειμένου και να βρεθεί στη θέση του δημιουργού. Τα αντικείμενα-εκθέματα γίνονται έτσι διαμεσολαβητές στην ανάπτυξη μιας διαλεκτικής σχέσης ανάμεσα στον νεαρό χρήστη και το Μουσείο.

β) Το παιχνίδι *Τι είμαι;* είναι συνδυασμός αινιγμάτων και αντιστοίχισης (Εικ. 6). Μια σειρά κάρτες περιγράφουν, με τρόπο παιγνιώδη και αινιγματικό, αντικείμενα, των οποίων οι φωτογραφίες παρατίθενται με τυχαία σειρά.

Εικόνα 6 Η εκπαιδευτική εφαρμογή «Τι είμαι;».

Σκοπός είναι η αντιστοίχιση των αινιγματικών περιγραφών με τις φωτογραφίες. Μέσα από το αίνιγμα, με απλό τρόπο, παρέχονται βασικές πληροφορίες. Η σωστή αντιστοίχιση δίνει όλα τα στοιχεία και τη σύνδεση με τη μόνιμη έκθεση μέσα από την εικονική περιήγηση.

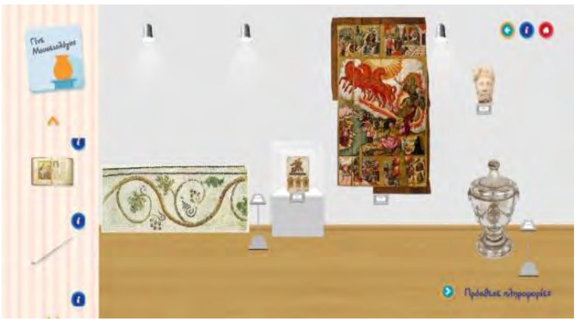
γ) Η εφαρμογή *Συναρμολογούμε τα σπασμένα αντικείμενα* είναι παιχνίδι παζλ. Ακολουθεί την ίδια αρχή με το παιχνίδι μνήμης που είδαμε πιο πάνω και προσφέρει τρία επίπεδα δυσκολίας (με 4, 8 και 16 κομμάτια αντιστοίχως), καθένα από τα οποία καταλήγει στον σχηματισμό της εικόνας ενός αντικειμένου της έκθεσης.

Στις εκπαιδευτικές εφαρμογές που περιγράφηκαν μέχρι τώρα, δεν υπάρχει μεγάλο περιθώριο αυτενέργειας. Οι παίκτες ακολουθούν τις οδηγίες ενός παιχνιδιού, με στόχο την ολοκλήρωσή του, η οποία είναι μονόδρομος. Οι πληροφορίες που πηγάζουν από τη διαδικασία σωρεύονται ως γνώσεις βγαλμένες από ένα «διαδραστικό εγχειρίδιο» (Δημαράκη 2008, 156).

Σε περιορισμένο βαθμό και ειδικότερα στην εφαρμογή *Με τα δικά σας χρώματα* ζητείται το προσωπικό στοιχείο, η προσωπική ματιά του χρήστη. Προκειμένου να δοθεί η δυνατότητα για αυτενέργεια και διάδραση, προχωρήσαμε στον σχεδιασμό μιας αρκετά απλής εφαρμογής, όπου, όμως, δεν υπάρχει η έννοια του σωστού ή λάθους.

Εδώ, στόχος είναι να δοθεί στο νεαρό χρήστη, μέσα από την ψηφιακή τεχνολογία, η δυνατότητα για προσωπική έκφραση, η ευκαιρία να ξεφύγει από τον περιορισμένο και περιοριστικό, εν πολλοίς παθητικό, ρόλο του επισκέπτη/δέκτη της μουσειακής αφήγησης και της πληροφορίας και να αποτελέσει οργανικό στοιχείο της, που επιλέγει και συναποφασίζει.

Πρόκειται για την εφαρμογή **«Γίνε Μουσειολόγος»**, που επιχειρεί να βοηθήσει στην κατανόηση του ρόλου του μουσείου (Εικ. 7). Ο χρήστης, βρίσκεται σε ένα περιβάλλον που θυμίζει εκθεσιακό χώρο. Εκεί παρουσιάζεται μια σειρά δέκα αντικειμένων τα οποία συνοδεύονται από την αρχαιολογική τους πληροφορία.



Εικόνα 7 Η εκπαιδευτική εφαρμογή «Γίνε Μουσειολόγος».

Εικόνα 8 Στιγμιότυπο από το εκπαιδευτικό πρόγραμμα «Η γέννηση του Βυζαντινού Μουσείου».

Ο χρήστης καλείται να σχεδιάσει μια δική του έκθεση: να επιλέξει τα αντικείμενα (όλα είναι σε σχετική κλίμακα), να τα τοποθετήσει (με τον ενδεδειγμένο, για κάθε αντικείμενο, τρόπο, π.χ. η φορητή ξύλινη εικόνα πρέπει να αναρτηθεί) και να γράψει λίγα λόγια για το σκεπτικό της έκθεσής του. Την έκθεσή του μπορεί να την αποθηκεύσει και να την στείλει, να την μοιραστεί κ.ο.κ.

Η συγκεκριμένη εκπαιδευτική εφαρμογή έχει υλοποιηθεί ήδη από το 2002 σε δραστηριότητα που ολοκλήρωνε το εκπαιδευτικό πρόγραμμα *Η γέννηση του Βυζαντινού Μουσείου*. Εκεί, οι μαθητές καλούνταν να οργανώσουν τη δική τους έκθεση με φωτογραφίες αντικειμένων από τις συλλογές σε φυσικό μέγεθος, με βοήθεια τα σχετικά δελτία καταγραφής-τεκμηρίωσης (Εικ. 8).

Οι παραπάνω εφαρμογές, καθώς και όλες οι ψηφιακές εφαρμογές του Βυζαντινού και Χριστιανικού Μουσείου που προβάλλονται από το διαδίκτυο, είναι προσβάσιμες και εντός της μόνιμης έκθεσης, αφού παρέχεται δωρεάν ασύρματη σύνδεση. Έτσι, τα παιχνίδια, όπως και όλες οι πληροφορίες, μπορούν να αξιοποιηθούν και κατά τη διάρκεια μιας πραγματικής επίσκεψης στον χώρο.

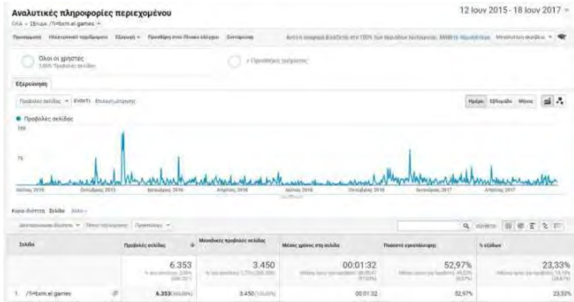
Συμπεράσματα

Η εμπειρία από το μικρό χρονικό διάστημα λειτουργίας της ψηφιακής πλατφόρμας του Εικονικού Μουσείου, αφ' ενός, και η πολυετής εμπειρία στον σχεδιασμό και την εφαρμογή μουσειακών εκπαιδευτικών προγραμμάτων, αφ' ετέρου, είναι η βάση για τα συμπεράσματα και τους προβληματισμούς που ακολουθούν. Οι ψηφιακές εκπαιδευτικές εφαρμογές που αυτή τη στιγμή λειτουργούν σε ιστοσελίδες δημόσιων και ιδιωτικών μουσείων παρέχουν μάθηση μέσα από την πληροφόρηση για τα μουσειακά αντικείμενα. Επομένως, αυτού του είδους οι εφαρμογές περισσότερο λειτουργούν ως ένα ευχάριστο «διαδραστικό εγχειρίδιο» παρά ως μια ευκαιρία για να έχει ο χρήστης μια ουσιαστική εμπειρία προσωπικής ερμηνείας και κατανόησης.

Οι χρήστες δεν είναι συμμετοχικοί, ούτε εκλαμβάνονται ως οργανικά στοιχεία στη δημιουργία ενός νοήματος. Η συνέργεια και η διαδικασία έρευνας και οικοδόμησης της γνώσης είναι πολύ περιορισμένη ή ακόμη και ανύπαρκτη. Αυτό υποθέτω ότι οφείλεται κυρίως στο γεγονός πως τα έργα που σχετίζονται με την ψηφιακή τεχνολογία και υλοποιούνται στο πλαίσιο χρηματοδοτικών προγραμμάτων όπως το ΕΣΠΑ έχουν άλλες προτεραιότητες και ανάγκες, και έτσι μικρό ποσοστό μόνο διατίθεται για τον σχεδιασμό και την υλοποίηση σύνθετων εκπαιδευτικών εφαρμογών (Γιαννούτσου 2015, 225-249). Ο χρόνος και οι πόροι είναι ιδιαίτερα περιορισμένοι κι έτσι οι εκπαιδευτικές εφαρμογές καταλήγουν να είναι ο «φτωχός συγγενής» των μεγάλων έργων.

Μια επιπλέον παράμετρος είναι το υψηλό κόστος της τεχνικής υποστήριξης που απαιτείται για τη συντήρηση αυτών των εφαρμογών, μετά την ολοκλήρωση της υλοποίησής τους. Έτσι, πολλά σημαντικά έργα αντιμετωπίζουν προβλήματα και αδυναμίες, ελλείψει έμπειρης τεχνικής υποστήριξης. Μια άλλη παράμετρος που χαρακτηρίζει την ψηφιακή τεχνολογία είναι η ανάγκη για διαρκή ανανέωση και αναβάθμιση των προγραμμάτων. Η χαμηλή χρηματοδότηση (ειδικά σε περιόδους οικονομικής κρίσης) δεν αφήνει, ωστόσο, τέτοια περιθώρια. Παρά τις δυσκολίες, υπάρχουν αξιόλογες προσπάθειες ψηφιακών εκπαιδευτικών εφαρμογών, αν και όχι πάντα διαθέσιμες στο διαδίκτυο, όπως παρουσιάστηκαν στη συνάντηση εργασίας του ICOM-CECA (Αθήνα, 13-14/1/17). Αναφέρω ενδεικτικά: **«Το ταξίδι του Τιμόδαμου»** από το Αρχαιολογικό Μουσείο Ιωαννίνων, την κλειστή μαθησιακή πλατφόρμα του Αρχαιολογικού Μουσείου Χανίων και το πρόγραμμα **«Γλαύκα»** του Μουσείου Ακροπόλεως.

Τα μουσεία, λοιπόν, θα μπορούσαν να συνεργαστούν, παρέχοντας την τεχνογνωσία και την εμπειρία τους, και να αποτελέσουν βάση για την εφαρμογή πιλοτικών ψηφιακών εκπαιδευτικών προγραμμάτων-παιχνιδιών, σχεδιασμένων από κοινού με άλλους επιστημονικούς-ερευνητικούς φορείς που ασχολούνται με την ψηφιακή τεχνολογία. Με τον τρόπο αυτό, ένα μουσείο μπορεί να καταστεί χώρος όπου θα μπορεί κανείς να βρει ποικίλες εκπαιδευτικές προτάσεις από διαφορετικούς κατασκευαστές. Η εμπειρία από τον σχεδιασμό και την υλοποίηση του συγκεκριμένου έργου κατέδειξε ότι είναι αναγκαία η αυτόνομη αντιμετώπιση των εκπαιδευτικών εφαρμογών ως τομέα μουσειακής ψηφιακής πολιτικής, και όχι απαραίτητα ως μέρους ενός ευρύτερου ψηφιακού έργου. Σε επόμενο στάδιο, θα μπορούσαμε να αξιοποιήσουμε τις δυνατότητες των ηλεκτρονικών παιχνιδιών με πολλούς χρήστες (multiplayer games) και διαφορετικά σενάρια, που επίσης υπηρετούν το τρίπτυχο φαντασία, περιέργεια και πρόκληση.



Εικόνα 9 Η στατιστική επισκόπηση του τελευταίου έτους (2016-2017) για τη σελίδα των εκπαιδευτικών εφαρμογών από τα Google Analytics.

Συνοψίζοντας, είναι απαραίτητος ο αυτόνομος και ανεξάρτητος σχεδιασμός ψηφιακών εκπαιδευτικών εφαρμογών, στο πλαίσιο των ευρύτερων επικοινωνιακών και εκπαιδευτικών πολιτικών του Μουσείου και πάντα σε συνάρτηση με τις συλλογές, τις εκθέσεις και τις άλλες δραστηριότητές του. Θα πρέπει επιπλέον να εξασφαλίζεται ο απαραίτητος χρόνος και οι αναγκαίες πιστώσεις για τον σχεδιασμό και την υλοποίηση των εφαρμογών, προκειμένου αυτές να καταλήξουν στη δημιουργία ενός περιβάλλοντος μέσα στο οποίο ο χρήστης θα μπορεί να αυτενεργεί και να προσφέρει τη δική του ματιά. Ο σχεδιασμός είναι απαραίτητο να ξεφεύγει από την κλειστή πολυμεσική εφαρμογή με προκαθορισμένο περιεχόμενο και να προσφέρει ένα ψηφιακό περιβάλλον που θα ενθαρρύνει τη διερεύνηση. Οι εκπαιδευτικές εφαρμογές, άλλωστε, αποτελούν ένα εύχρηστο εργαλείο για τους εκπαιδευτικούς που επιθυμούν να υποστηρίξουν τον σχεδιασμό μιας εκπαιδευτικής δράσης σε συνεργασία με το Μουσείο.

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PROJECT DIGITAL ENHANCEMENT OF PELOPONNESE CASTLES: ASSESSMENT, IMPACT, PERSPECTIVES AND CHALLENGES

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Περίληψη/ Abstract

Η ψηφιοποίηση της πολιτιστικής κληρονομιάς τείνει να γίνει βασικός πυλώνας της αρχαιολογίας, συμπληρωματικός κάθε παραδοσιακής μεθόδου τεκμηρίωσης, ανασκαφής, αποκατάστασης και διαχείρισης μνημείων καθώς καλύπτει αποδοτικά και αξιόπιστα πολυδιάστατες απαιτήσεις της παραδοσιακής αρχαιολογίας σε κάθε στάδιό της. Ο σχεδιασμός της αρχαιολογικής αφήγησης σε έργα ψηφιοποίησης αποτελεί εντυπωσιακή διαδικασία με σημαντικές προοπτικές αλλά και αρκετά εμπόδια που πρέπει να ξεπεραστούν. Η Ψηφιακή Ανάδειξη των Κάστρων της Πελοποννήσου ήταν ένα έργο τεκμηρίωσης 105 οχυρωματικών θέσεων και διαδικτυακής ψηφιακής προβολής τους. Στο πλαίσιο του έργου έγιναν ψηφιοποιήσεις υλικού, αποτυπώσεις με σύγχρονες ψηφιακές μεθόδους, δημιουργία τρισδιάστατων αναπαραστάσεων, εικονικές περιηγήσεις, ιστότοπος και εφαρμογές σε έξυπνες φορητές συσκευές για την διάχυση της πληροφορίας και την επιτόπια ξενάγηση στις θέσεις. Στο παρόν κείμενο θα παρουσιαστεί ο προβληματισμός από την εκπόνηση ενός τόσο εκτεταμένου έργου σχετικά με τον αντίκτυπο και τις προοπτικές σε εκπαιδευτικό, ερευνητικό, τουριστικό και κοινωνικο-οικονομικό επίπεδο με παράλληλη αναφορά στις δυσκολίες και προκλήσεις που προέκυψαν.

Archaeological digitisation turns to be a basic pillar of archaeology, supplementary to any conventional documentation, excavation, restoration or heritage management work because it covers efficiently and reliably multidimensional demands in every stage of traditional archaeology. The design of an archaeological narrative in digitisation projects constitutes an impressive procedure with great future but still many obstacles to overcome. The Digital Enhancement of the Peloponnese Castles was a project about the documentation and web digital promotion of 105 castles. The project included the digitisation of material, surveys with up-to-date digital methods, the creation of 3d representations, virtual tours, a website and smart phone applications in order to disseminate archaeological information and to support actual visits at the castles. In the current paper project's experience will be presented as a way of questioning about the impact and perspectives of such an expanded documentation effort in educational, research, touristic and socio-economic terms with parallel reference to the emerging difficulties and challenges.

Keywords: Virtual Archaeology, 3D reconstruction, Data analysis and visualisation

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Introduction

The idea of a collective digital platform for fortified architecture in Peloponnese, which would both cover a large gap in archaeological knowledge and would also make the public aware of these unique heritage resources, was first conceived within the former 25th Ephorate of Byzantine Antiquities. The project was carried out from early 2014 until December 2015. It has resulted in a platform that features information on 105 fortified sites in the regions of Argolid, Arcadia and Corinthia (Fig. 1). The project came later under the administrative supervision of the Argolid Ephorate of Antiquities.

The project combined field work (surveys, site-inspections, surface excavations etc.), bibliographic and original research on fortified architecture by a multidisciplinary team of archaeologists and architects. Research conclusions were elaborated and presented both to experts and to the public through a website (http://ecastles.culture.gr) with the aid of contemporary interactive methods of sharing archaeological information (Athanasoulis *et al.* 2015). Digital surveys (scanning, geodesy, geo-referencing, aerial and terrestrial photogrammetry) became valuable and time-efficient means of collecting huge amounts of information that was carefully elaborated and blended with traditional-sourced material.

Figure 1 The project includes 105 fortified sites in the Argolid, Corinthia and Arcadia.

Combined architectural evidence in the field, archive information, historical photos and archaeological research were presented into graphic reconstruction models. The creation of three - dimensional models of selected castles was a main pillar of the effort to distribute and simplify archaeological information. The hypotheses that emerged through the project's tailoring and implementation, will hereinafter be developed and they should be open for further discussion in future projects.

1. Assessment - Impact

The Digital Platform for the Promotion of the Castles of the Peloponnese intends to affect a) the educational process concerning fortifications b) the change of visitor's experience and interaction and c) the protection of the monuments themselves through the process of gathering, elaborating and storing documentation material.

1.a The educational process

A basic concern of the research team was to lead the visitor to a journey of recognition and deepening in the knowledge of defensive architecture. Thus, the articulation of the web platform has focused on three main thematic categories, namely "learn", "explore" and "live".

The historical and archaeological context of military architecture is broadly and thoroughly presented through the options that the thematic menu **"learn"** in the homepage offers. (Fig. 2). Web platform visitors may access historical information on the Peloponnese from the early byzantine era till the years of the Greek Revolution, while they learn about the Peloponnesian geographical units and the connection between the presented monuments and the main road networks. Another interesting topic presented is the role of the visual connections and sight-lines between monuments within these geographical units. Moreover, architectural information offered includes the different types of military constructions found in the presented regions, the components of an active or passive defensive system and some main points in the evolution of fortifications.

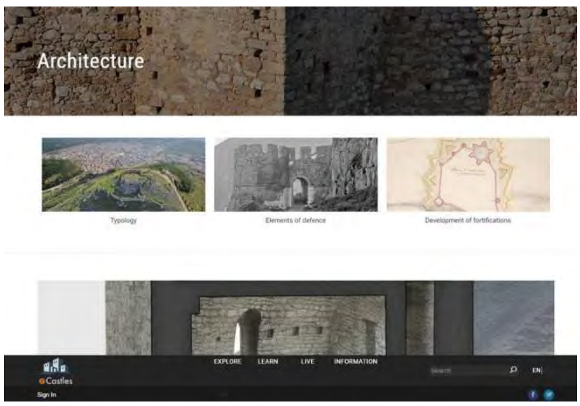

Figure 2 The thematic menu "learn" is enriched with general information on fortifications.

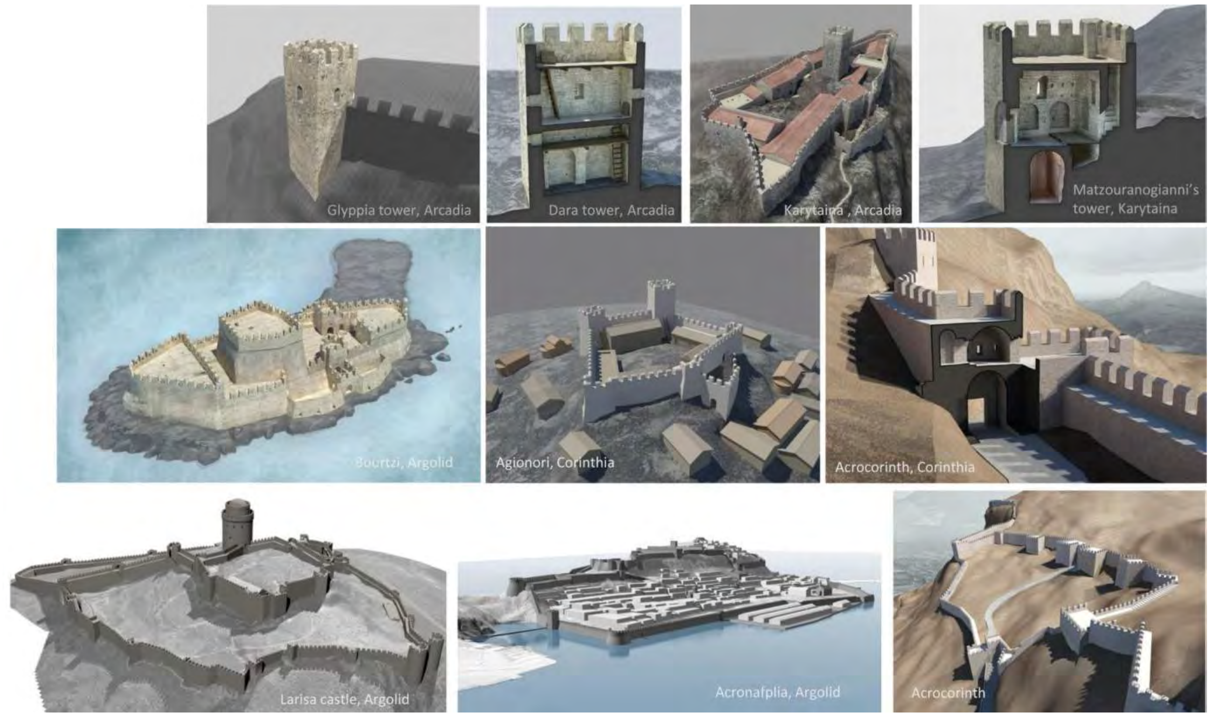

Figure 3 3D virtual representations of selected castles.

The users obtain practical information about the construction and the maintenance of the fortifications, the art of war and the role of fortifications in the everyday life of medieval people. Additionally, they are equally informed about historical art representations of fortifications.

Beyond the contextual knowledge, the user has several opportunities to explore the archaeology, history and architecture of the individual presented monuments by choosing from the thematic menu **"explore"** in the homepage the path to a specific monument either via a map, or a timeline, a digital library or a catalog. In this case, an archaeological-architectural description for each monument is available, along with a historical introduction and several other information, such as its coordinates and position, the time period when it was built, bibliography, legal protection and access information. The presentation of the monument is vitally enriched by photographs and drawings, while 3d representations with informative material (hotspots) are available for a number of significant monuments (Fig. 3).

Apart from the educational role that the aforementioned archaeological and historical presentation offers, the younger users can assimilate the obtained knowledge with the help of educational applications that are included in the thematic menu **"live"**. These include several quiz games, a participation-application and attractive interactive applications, such as "Treasure hunting", "Built your castle", "Explore the castle". With these educational options, the user can learn and at the same time be entertained and motivated.

A major contribution of the site is that it offers educational options to users of all ages. The information on general topics or specific monuments as well as the educational applications have been graded to suit different educational levels or types of users (teachers, pupils, students, families, researchers etc.). For example, the hotspots of the 3d reconstructions can be very helpful for users that seek specific information about a monument, while the reconstructions themselves provide younger users with a better overall understanding of the monument.

1.b Changing visitor's experience

Digital enhancement is additionally translated in terms of augmentation of people's interest on fortified architecture that can be multi-oriented: scientific, educational, touristic, cultural or even environmental. The archaeological information is being exhibited in a new and more attractive manner that creates an alternative experience of viewing either neglected or the popular and frequently visited monuments. It is equally important for groups of people with physical restrictions to access the site. The structure of the platform allows unlimited access. It does not impose restrictions on reading, viewing or learning about the history and the architecture of fortification. It is an open source of scientific information, yet with a leveled and well-structured flow.

The platform creates a new reality, established by new relationships between the subject (viewer) and the object (monument); unlimited movement from one place to another, continuous flow, change of focus and scale. The spatial boundaries between the object and the viewer no longer exist. New boundaries include larger geographical areas, meaning that the notion of walking distance is overpassed by an expanded network of distant objects.

It enhances a personal experience, based upon each viewer's point of view. Itineraries are generated by the personal interests, level of knowledge, and area of expertise of the viewers. The platform allows for a cross-disciplinary engagement between a variety of media; texts, drawings, surveys, images, reconstructions (Fig. 4). Therefore, it constitutes a dynamic structure which offers the visitor multiple choices in order to draw information, construct a full image and finally get a whole experience of the monument.

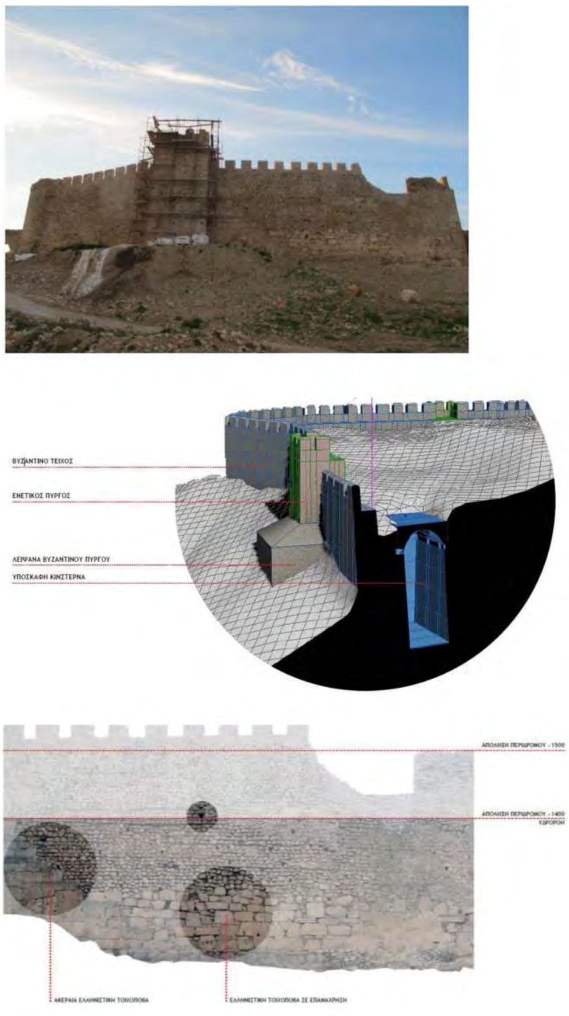

Figure 4 Documentation material supplementary to conservation work.

1.c Monument protection

The digitisation project also serves as an inventory of heritage resources and aids the prevention of archaeological memory loss. The rapid and serious deterioration of tangible architectural heritage is an inevitable reality caused by human and weathering factors, especially when referring to neglected, inaccessible or difficult-to-be-managed fortifications. The contribution of digital inventories, beyond the obvious collection of all usual archival information, is the creation of original documentation and analysis material from site inspections and surveys. These data are stored and easily retrieved and transmitted for future queries within the supporting database.

Additionally, documentation efforts and the creation of strong information management systems are effectively integrated within the conservation process (Letellier 2015). Thus, the platform and the whole process of meticulous indexing the castles is catalytic for the recognition of the existing stock of monuments and, more generally, for the proper appreciation of fragmentary archaeological material (Wheatley 1995). This process lead the Ephorates of Antiquities in charge to a first assessment of the monuments' current state, an evaluation of their significance, and also a better understanding of the specificities and requirements of each castle. It also supports basic categorisation and interpretation of the castles and the drafting of urgent safeguarding interventions towards integrated conservation and enhancement master planning.

The conservation of the monuments is certainly related not only to the protection body's initiative but also to public awareness. The web-visitor is a potential site-visitor that gets informed and attracted through the platform, as fortifications combine unique merits of natural, historical and architectural significance. People are overwhelmed by the existence of such a variety of fortified monuments, mostly unknown and neglected. This first interaction with the public leads to increased visitor's traffic and consequently raises public awareness for the protection of the actual monuments. As a result of visitors and consequently ticket augmentation, the economic outcome will return to monuments restoration actions.

2. Perspectives

Despite the apparent limitations of its implementation, the project has resulted in the accumulation of a significant amount of both documentation material and of experience. Both attain a great potential to be further exploited at the educational, research, tourist and socio-economic level.

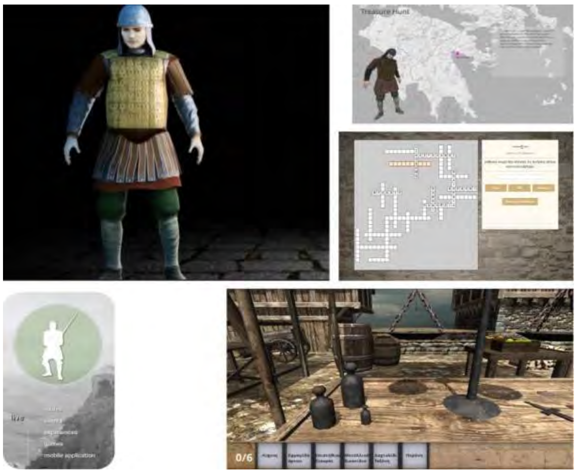

Figure 5 Educational activities developed for young users.

2.a Educational perspectives

The significance of archaeology in teaching history at the level of primary and secondary education has long been recognised (Μαστραπάς 2001, Παπανικολοπούλου 2013). In the last few years, new technologies have contributed greatly to the enrichment of the educational process (Κουνέλη 2008, Ψυχογυιού 2009). The apparent educational benefits could play a leading role in the evaluation of the present project. This is due to the fact that even if it presents monuments from the geographical units of Argolid, Arcadia and Corinthia, it highlights in one webpage several general topics concerning fortified constructions. These topics include history, archaeology, topography, architecture, art, aspects of war and of everyday life, technological evolution and interaction between countries, all in an up-to-date computer environment.

An educational perspective regarding the Digital Promotion of the Peloponnese castles could be the opportunity for a pluralist approach of school history (Κυρκίνη 2001) and for experiential learning, which is a requisite for student centered learning. Students cease to be passive learners as this site can be used as a tool for interaction in the classroom. Pupils and students can learn in a more profound way what they read in their history books by the visualisation of courses with the use of the offered games and the relevant photographs, videos, panoramas, designs and 3d applications of specific monuments (Fig.5).

Experiential learning can also be achieved via educational virtual tours (Fig. 6). These should come after an appropriate preparation in the classroom and use of the webpage and may follow the virtual itinerary that the site proposes at the sections devoted to the 3D reconstructions. Alternatively, pupils and students may identify and examine several of the architectural details of fortified constructions.

Figure 6 Classroom interaction on experiential learning.

In addition, such features may be actually encountered during live educational tours, either in Greece or in foreign countries with rich fortification traditions and historical connections to Greece (such as France, Italy etc.). These tours allow comparative understandings of fortification elements from different countries and therefore facilitate a meticulous knowledge of the cultural context of these constructions.

Moreover, this platform could be used as an opportunity for the development of further educational activities, such as the "adoption" of a certain monument by groups of pupils and students, following the example of "Diazoma" a learned society focusing on the protection and promotion of ancient theatres in Greece (http://www.diazoma.gr visited on 23/9/2017) or eTwinning, a platform for the collaboration between schools in Europe and the implementation of interesting educational projects (www.etwinning.net visited on 23/9/2017).

2.b Research perspectives

The potential role of the Digital Enhancement of the Peloponnese Castles in research on fortifications is significant, too. Firstly, it should be considered as a digital corpus for all the medieval and post medieval fortified monuments of the geographical regions of Argolid, Arcadia and Corinthia. Thus, it is a great step towards the creation of a more complete digital corpus with all the relevant monuments throughout Greece. Even if the scientific need for such a corpus has been intense for many decades, the studies that have taken place till now concern only specific monuments or groups of monuments of a certain region or time period. Such a project that would include Greek fortified constructions would facilitate the extraction of broader conclusions, after comparisons and categorisations between the monuments.

Furthermore, and beyond the apparent contribution to research, the integrated registration of the monuments as a corpus would automatically ensure monuments' protection from future misuse or further natural wear.

Another contribution of the platforms to research deepening is that by combining traditional forms of documentation (e.g. texts, photographs and designs), with modern ones like panoramas, videos, 3D representations, it permits a more complete presentation of each monument. Equally important for recent research is also the fact that in this documentation, new bibliography is included, along with the latest conclusions of the archaeological survey.

The whole documentation effort also offers the opportunity for the extraction of interesting conclusions by combining different information and search criteria (time period, region, architectural typology). Such a complete documentation combined with the opportunities for comparative research has a high motivation potential for further studies by interested researchers.

2.c. Tourist, cultural and socio-economic prospects

Cultural heritage has played an important role and still holds a great potential in the tourist policies and economic development of Greece. The website ecastles.culture.gr constitutes a digital documentation tool and at the same time a digital communication tool that can be used from people motivated by various interests to learn about history, geography and defensive architecture of Argolid, Arcadia and Corinthia.

Beyond the tangible cultural heritage, the website also aims to motivate the users to learn more about the intangible cultural heritage which is also an important constituent of heritage and can be significant for the development of a new touristic model which focuses on individual interests (Πούλιος & Τουλούπα 2015). In order to achieve this model, the platform aims to create a new and completely personalised visiting experience. Drawing the idea from the the French 19th century Éxpedition du Morée, visitors and tour operators can create their own routes based on scientific, cultural, historical, archaeological, geographical, physiographic, social, recreational and anthropocentric interest.

Apart from wayfinding to specific sites, the visitor can create longer routes between castles and other monuments and sites (Fig. 7). These routes could include not only well or less known fortifications but also visits to other archaeological sites. Tourists could also satisfy their cultural needs by participating in events or activities organised by local communities. For example, a visitor of Nafplion city could not only visit the existing defensive remains of the city (Akronauplia, Bourtzi, Palamidi) but also well-known fortifications which lie at a small distance, like the Castle of Argos or less known fortifications as for example Kiveri castle. Tourists with distinct cultural interests may participate in events or activities organised by local communities. For example, the visitors of Nauplion could also attend or even participate in the new annual event of the "Nauplion Castle Run".

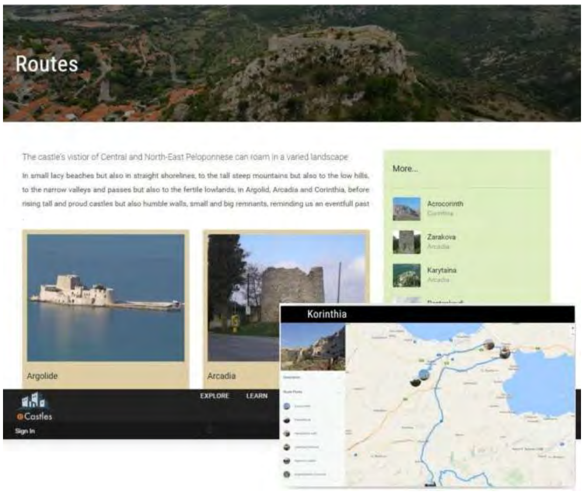

Figure 7 Planning of fortification-centered touristic routes.

This kind of tourist model can bring up less renowned places and monuments and may lead to a number of multilevel effects. First of all, the growth of cultural awareness among local populations is quite important, as the residents' cooperation and consent is essential for the success of the model (Maistrou 2009). The wise management of regional cultural wealth and the increasing need to protect and promote heritage can contribute to the sustainment of economic, cultural and social resources and can play a key role in the economic recovery of the areas in question (Timothy 2011; Comer & Williams 2011). In other words, the platform may aid local communities to form a sustainable planning strategy, integrate the monuments in modern life and raise their tourist revenue. The increase in visitor capacity and tourist traffic opens new and diverse job opportunities and strengthens the socio-economic state of local societies.

Additionally, revenue through increased visits may lead to further cultural development. The revival of older traditions and the creation of new cultural performances could link local societies to their past and establish new inter and intra-communal links. For example, the annual organisation of a "hidden treasure game" in the settlement and castle of Karytaina may introduce a new type of cultural experience, addressed to groups of various levels of age and culture.

The platform is also going to redefine the ways in which tourists perceive archaeology. Consequently, visitors will adapt their tourist interest and develop new routes for the exploring of archaeological information through the integrated virtual guidance. In the town of Nauplion, for instance, the visitor is now able to comprehend that the existing defensive remains consist a composition of a complex fortification system for the entire city. As a result, s/he is not only going to visit Palamidi, but may be seriously tempted to find her/his way into the urban tissue so as not to miss the Xira Gate and Akronauplia that have been usually neglected.

2.d Heritage management perspectives

Through the digitisation project the foundation for specialised master planning has been set and heralds a planning process with great potentials. This planning will be a logical progression from collection of information, to assessment-analysis and final decision making. (Demas 2000). More precisely, the protection body in charge, in this case the regional and central services of the Greek Ministry of Culture, possesses currently all the necessary material for the interpretation of the monument and the evaluation of its condition so that it may implement targeted heritage management policies and interventions.

The updated digital survey material (terrestrial and aerial 3D scanning data, geo-information, aerial photography, 3D virtual reconstructions, collected bibliography and archives, indexing of finds etc.) in most of the castles that have been documented (Akrocorinth, Kiveri, Larisa, Karytaina etc.) can be used as such, for future excavation and restoration works. The high level of elaboration of such documentation provides valuable second-stage information on the pathology and the historical and architectural phases of the monuments.

On the other hand, the Service of Antiquities in charge can estimate and take into account crowd's preferences (visitors and stakeholders) and interaction with the monuments through monitoring of the crowd’s interest and digital flow to specific monuments in the platform and through social media feedback.

Such data may help the shaping and/or modification of regional heritage policies so as to suit the interests of both potential actual visitors to the monuments and of other heritage stakeholders. Thus, future management efforts for the enhancement of the fortifications will include not only actual interventions on the monuments but also the design of new digital thematic applications for their virtual promotion.

2.e Perspectives of projects’ expansion

All the aforementioned perspectives related to the exploitation of the existing platform will be weak or even impossible without the necessary expansion of the project. The first audience feedback after the web-platform was launched highlighted the importance of completing such a time and effort consuming project. It was also pointed out that the project needs to continue to add and disseminate new data on castles, both by updating the existing entries and by adding new ones. The scholarly, educational, tourist and cultural interest of the public leads to a gradually increased web traffic and a steady raise in the number of downloads for the mobile applications. It is then vital to complete the documentation of fortifications in the Argolid, Corinthia and Arcadia and to convince more Ephorates of Antiquities to join this initiative.

3. Challenges

3.a Research challenges

The implemented project underlined the great need for monuments to be catalogued and further documented. It has been hampered by several factors, such as the dispersion of the monuments in different locations, their great number and the bad state of preservation that are usually in.

The presentation of all these monuments on a single platform also revealed that there is a great lack of information and thorough survey for some defensive constructions in comparison to others. In some cases, there are only speculations about the precise dating or plan of the constructions due to limited or non-existing field and excavation surveys. Thus, there are still challenges in research for a number of monuments that are presented at this site, as a lot of information remains to be filled in. This unequal treatment of monuments also creates a wider gap in the overall field of research on fortified architecture. Further focus on specific monuments that have not been studied historically and archaeologically yet could also help to achieve a broader view of these constructions and to reach conclusions over medieval and post medieval fortified architecture in Greece (Fig. 8).

3.b Platform management challenges

Despite digital evolution and impressive accumulation of 3D visualisations, criticism arises in the circles of virtual archaeology reflected in several recent publications (Richards et al. 2013; Scopigno et al. 2017). This speculation is related with the problem of conserving and managing the vast quantities of heritage information data that has to phase three important challenges: fragmentation, reliability and longevity (Addison et al. 2008). The Platform for Digital Promotion of the castles has ensured data entry with scientific reliability as an official action of multidisciplinary team of scientists supervised by the Ministry of Culture. It is nevertheless vulnerable in terms of fragmentation, because it constitutes an individual effort of a single Ephorate, namely a regional service of antiquities, concerning monuments within its jurisdiction.

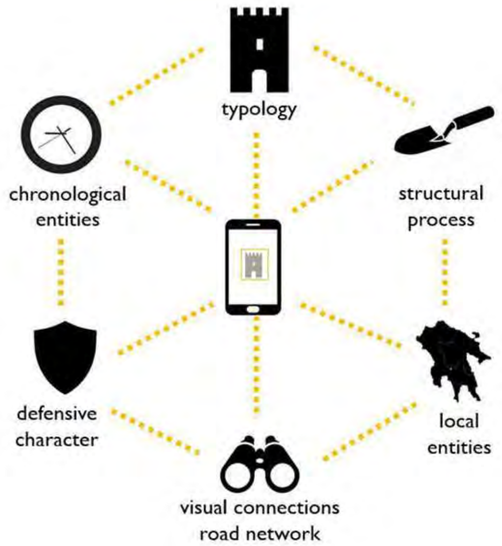

Figure 8 Expansion of comparative research studies.

More Ephorates and individual researchers should join this initiative, because research on fortifications has to be expanded. In terms of longevity as well, platform's data has to be tested because after a short period of time the data storage will pass to the future general Cloud system management of the Ministry.

The Digital Promotion of the Peloponnese Castles was co-funded by the National Strategic Reference Framework of the European Union and by the Hellenic Government. The first months of its complete launching it has received encouraging comments from the audience, a fact that proves that digitisation efforts are covetable and consequently necessary. However, when the project ends, the long-term maintenance of the platform and the necessary continuation of the project are up to the understaffed regional Ephorates. The end of the project of course doesn't mean the end of documentation and the huge amount of unprocessed information has to be managed. Only a small indicative selection was published in the web (Fig. 9). Therefore, the Archaeological Service is responsible to invent alternative ways of managing the platform, by responding to the increased interaction of public and by uploading updated research results. A possible solution could be the establishment of a more active participation of the audience -scientific and volunteering- under the Ministry of Culture's scientific supervision.

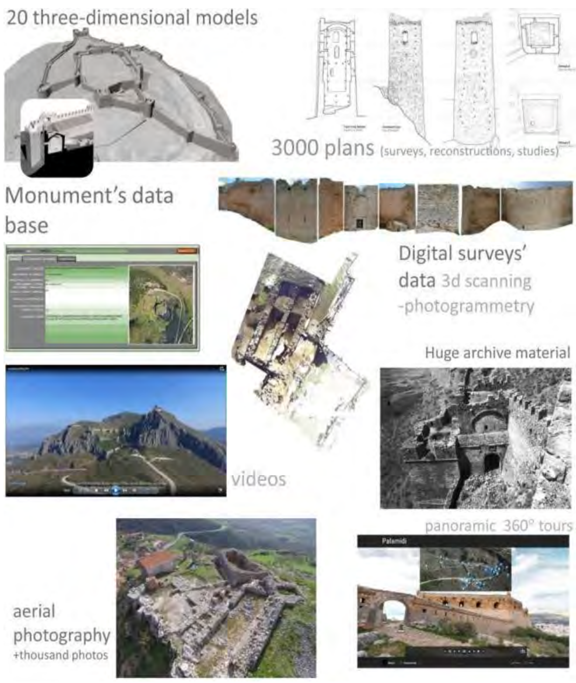

Figure 9 The various types of documentation data.

3.c Heritage management challenges

Beyond the management of digital resources, the most challenging task is the management of the natural fortification sites (Fig. 10), as it embeds the issues of fragmentation, big geographical diaspora, difficult accessibility and connection, high level of destruction or alterations, spatial and historic perplexity etc. (Athanasoulis *et al.* 2015).

Therefore, there is an urgent necessity for heritage master planning at the macro-scale for the ensemble of monuments. This includes the drafting of a list of prioritised interventions (emergency restoration measures and long-term site management) which should follow an appropriate monument documentation.

The information so far collected within the project is a valuable assessment tool for the establishment of protection degrees for monuments that had been previously neglected or for integrating the master planning for vulnerable defensive complexes in wider urban planning strategies.

Furthermore, the platform increased public awareness on defensive heritage, which in its turn prompts the Ephorates and other Protection Bodies to apply preservation measures, to draft master plans for the monuments that have been brought to public attention, to reinforce safety measures in the archaeological sites and to draw specific tourist and cultural routes.

The monuments presented in the platform used to belong to the jurisdiction of the 25th Ephorate of Byzantine Antiquities of Arcadia, Argolid and Corinthia which covered half of the Peloponnese in terms of geographical space. After the recent Ministerial reformation and the reorganisation of the Ephorates, the monuments belong to three separate geographical entities under three different Ephorates of Antiquities.

These Ephorates and the rest of Peloponnese public authorities have to closely collaborate in drafting a common and unified master planning in order to enhance the physical aspects of the monuments and the sense of belonging to a web of fortifications of the greater Peloponnese region.

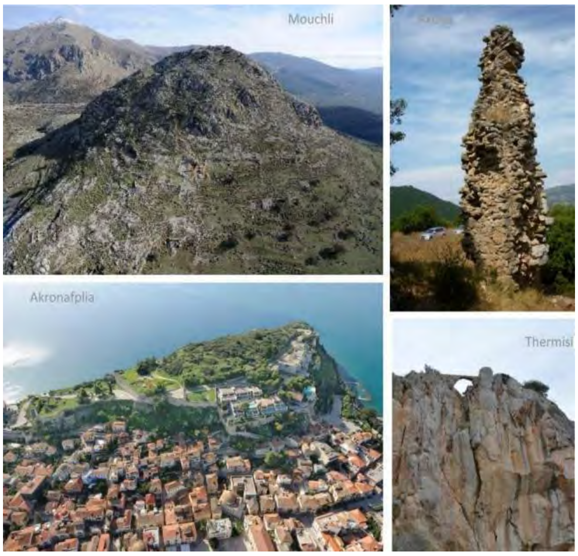

Figure 10 Different fortification types with various Management and conservation issues.

Conclusions

By presenting the attractive aspects of defensive architecture, the fortifications are perceived to the wide audience as echoes of medieval past, vivid historic lands, fascinating worlds of great combats, symbols of identity and belonging, places of natural contemplation or recreation places. From the other hand, the specialised researchers can be attracted by the enriched layering of historical phases. The monuments can be perceived as research-worthy micrographs of everyday life, or unique samples of architecture, elements of a wider defensive system with great historical and geopolitical importance, or masterpieces of war technology.

Regardless of the specific aims of web-visitors and despite the difficulties to be overcome or the extant gaps to be fulfilled, research institutions and heritage curators are responsible to design and implement such broad digital strategies for groups of monuments, so as to share archaeological knowledge, promote culture, generate the safeguarding and protection process and facilitate the transmission of heritage to future generations.

Given that the essential purpose of visual projects is to “augment” and boost reality, not to substitute or neglect reality, the digital platforms should contribute to the conservation of the actual monuments. The current effort should be a beginning for the establishment of a unified system of documentation, indexing, assessment and managing of the impressive fortified heritage of Greece.

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IS USER PARTICIPATION FEASIBLE IN CULTURAL HERITAGE ENVIRONMENTS?

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Περίληψη/Abstract

Η συμμετοχική κουλτούρα στο πεδίο της πολιτισμικής κληρονομιάς είναι μια πρόσφατη τάση που ακολουθεί την τεράστια επιτυχία των κοινωνικών μέσων. Σε αυτή την εργασία διερευνούμε το πόσο εφικτή είναι η εφαρμογή συμμετοχικών τεχνικών σε ψηφιακές πλατφόρμες πολιτισμικής κληρονομιάς. Προσπαθούμε να προσδιορίσουμε και να αντιμετωπίσουμε συγκεκριμένες προκλήσεις που ανακύπτουν σε συμμετοχικά ψηφιακά περιβάλλοντα και αφορούν θέματα πολιτισμικής διαχείρισης. Ο ρόλος των συμμετοχικών πλατφορμών στην αρχαιολογία είναι ένα ενδιαφέρον πεδίο έρευνας, καθώς μπορεί να ενεργοποιήσει το ενδιαφέρον του κοινού και να παρέχει ψηφιακές λύσεις σε αρχαιολόγους επί του πεδίου. Προσπαθώντας να απαντήσουμε σε αυτές τις προκλήσεις μελετήσαμε πρόσφατα ψηφιακά εργαλεία που επιτρέπουν τη συλλογή υλικών και άυλων δεδομένων, την ελεγχόμενη διάχυση πληροφορίας στο ευρύ κοινό και την ασφαλή ανταλλαγή δεδομένων μεταξύ μελών μιας ερευνητικής ομάδας. Η μελέτη μας προτείνει ότι μια τέτοια αλληλεπίδραση μπορεί να είναι ευεργετική για την αρχαιολογική έρευνα, την ψηφιοποίηση, τη διατήρηση και τη διάχυση περιεχομένου.

Participatory culture in the cultural heritage domain is a recent trend following the enormous success of social media. In this work we investigate the feasibility of applying participatory techniques in digital cultural heritage platforms. We try to identify and address specific challenges that arise in participatory digital environments concerning cultural heritage management issues. The role of participatory platforms in archaeology is a challenging subfield of research, as it can activate broad public awareness and it can provide digital solutions to archaeologists in the field. Attempting to provide an answer to those challenges, we studied recent digital tools that permit tangible and intangible cultural data collection, controlled dissemination of data to the broader public in a friendly manner and trusted data exchange among the members of a research group. Our study suggests that such an interaction can be beneficial for archaeological research, digitisation, preservation and dissemination of content.

Keywords: User Participation, Web-based Digital Platforms, Cultural Heritage, Archaeology, Smartphone Applications

Introduction

Participatory culture in technological applications has proven its strength in numerous cases in the last decade. Facebook, Instagram and Twitter are participatory platforms where users contribute data fundamentally. The main advantage of such platforms is the enormous amount of data produced by millions of people each second. This feature could be exploited in the cultural heritage domain. Morgan and Pallascio (2015, 263) suggest that “digital heritage incorporates the performance of heritage through acts of self-curation that collect images, video, hashtags, text, and other media”. Liew (2014, 1) investigates the need for cultural heritage institutions to “create a culture of participation around their digital collections and services”. Cultural heritage management could benefit from public participation in processes like the digitisation of tangible and intangible cultural information, digital preservation and direct public sharing of cultural documents.

When a platform provides users with the opportunity to upload self-generated content, considerable issues may arise (Oomen & Aroyo 2011). Participatory digital platforms face several challenges in terms of data soundness and accuracy, data moderation and everyday maintenance, data privacy and security or intellectual property rights. Platforms offering participatory services should ensure controlled access to cultural content stored in their databases. In order to entrust the system, users (experts or not) should be persuaded that their contribution will not be accessible or manipulated by others without their permission. Especially in archaeology, data are very difficult to be obtained and disseminated to the research community, as aptly discussed in Huvila (2011) indicating “the need for a platform for archiving and (or) making available the legacy data and developing an infrastructure for on-going and future research”.

In this work we focus on participatory digital platforms, which are more generic than crowdsourcing environments. In comparison to the latter, participatory platforms are not limited to the specific goals that institutions set. In order to measure the applicability of active user participation in cultural heritage participatory platforms, we use as a case study *Culture Gate*, a digital platform that provides cultural heritage digital services online with the participation of a large audience of users, both experts and amateurs. We conducted an evaluation of the system with the help of cultural heritage management professionals.

Culture Gate addresses all types of virtual heritage as defined by Ferguson *et al.* (2010). The platform collects small portions of information from many users which is stored, organised and presented to platform visitors. The system adopts an innovative way to display cultural information as pins on a geographical map, while hosting various smartphone applications concerning cultural heritage. Among these, we note *Culture Gate Collector*, a mobile application that facilitates the collection and preservation of cultural by specialists operating on outdoor locations (e.g. archaeologists).

1. Relevant research

Public archaeology aims at "engaging the public in order to share archaeological findings and/or promote stewardship of cultural resources or to otherwise make archaeology relevant to society by providing the public with the means for constructing their own past" (McDavid 2002a, 2). Digital public archaeology is the refinement of public archaeology that deals with web-based technologies, which can be used "to gather contributions of 'crowd-sourced' archaeological content; to share and discuss archaeological news and discoveries; foster online community identity, situated around the topic of archaeology and wider heritage issues, or to elicit financial support" (Richardson 2013, 1).

A number of examples have introduced various public, crowdsourcing or participatory cultural heritage digital tools and projects (Roussou *et al.* 2016):

- The *Heritage Together* project has developed a web platform "through which members of the public can upload their own photographs of heritage assets to be processed into 3D models using an automated photogrammetry workflow" (Miles *et al.* 2014, 361).
- *Archaeopedia 3D* (Forte 2009) is an ongoing project that will enable researchers, faculty members, and students to work collaboratively on projects of cyber-archaeology and cultural heritage.
- *MicroPasts* (Bevan *et al.* 2014) is a multi-application crowdsourcing project that enables both community-led and massive online contributions to high quality research in archaeology, history and heritage.
- *Know Your Place* (Insole & Piccini 2013) is a web-based tool that engages local communities in shaping the stories of their neighborhoods by allowing contributors to add media and metadata, thus producing archaeologically relevant information.
- *Day of Archaeology* project (Richardson 2014) argues about the advantages and disadvantages of creating an online public engagement project for public archaeology.
- *Ancient Lives* is a project that asks volunteers to transcribe ancient Greek text on fragments from the Oxyrhynchus Papyri collection (Williams *et al.* 2014).
- *Megalithic Portal* urges users to contribute photos of megalithic monuments in Europe (http://www.megalithic.co.uk/index.php).

Further systems use the power of social media for sharing archaeological data (e.g. Morgan *et al.* 2010).

2. Challenges and Issues

Embracing the culture of active user participation in cultural heritage platforms poses a series of challenges and issues. The main question concerns the feasibility of such systems, not in terms of technical implementation, but in terms of practical issues arising from their daily operation.

A successful participatory platform will constantly attract new users eager to use its services leading to a continuously increasing maintenance workload. How manageable could such a situation be, even if there is a reliable and efficient moderation plan in action? The project team should consist of many moderators to be able to cope with the daily moderation tasks. Additionally, a high level of traffic means that the necessary equipment would increase the financial costs in order to be upgraded. Increasing costs in personnel and equipment would make such a platform unfeasible, if additional revenue sources are not to be found.

The dissemination of archaeological data to the research community and the broad public is an important challenge (Huvila 2011). A participatory platform with a broad pallet of services, such as direct social media connectivity, discussion forums, serious games, interactive maps and multimedia content, can attract various user groups, ranging from experts to simple enthusiasts.

A vital issue in participatory platforms is the number of users (experts or not) that are willing to devote time in order to upload contributions. This issue is even more critical in the discipline of archaeology. Due to the limited availability of archaeological data (Huvila 2011), researchers invest much of their time on obtaining and archiving relevant content for their research purposes. Could they rather be persuaded to upload content onto a participatory platform? And if they can, could participation be extended to the wider public to contribute informal data and personal sources? Providing users with the appropriate tools to construct their own past could be an important reason for increased public engagement into content contribution (McDavid 2002a).

However, even if a number of archaeology experts or enthusiasts are persuaded to contribute content, how can a system guarantee their long-term engagement? Although it is very difficult to motivate users to contribute information, if we take into account that such a process promotes a sense of community, then it is possible that awareness about the well-being of the system can be raised and engagement maintained.

Another important challenge relates to the number of contributions. While it is highly desirable to have as many contributions as possible, a significant percentage of them could be noise, thus posing an unnecessary overhead to the system and diminishing its credibility. Is it feasible to eliminate the percentage of contributed noise, even if we apply filtering mechanisms, like moderation and authoring? Authoring deals with the issue of inaccuracy efficiently, but it costs in time (an authoring procedure could take too long) and the system must attract a large number of auditors from various disciplines to help in this procedure. Lack in auditor numbers could make the authoring procedure void.

Creating a secure environment for users to interact with the system and upload their contributions poses another significant challenge to online participatory systems. Trustworthiness is essential, as users must be ensured that their content will not be accessed and manipulated by others without their permission. Only then, they will be persuaded to upload their content to the platform.

Intellectual property rights issues could arise in systems that rely on user-generated content. Contributors could upload content copying third party intellectual work without permission or appropriate source declaration resulting to legal actions against the platform. Securing full ownership of the uploaded content by the contributors reduces the problem, but unpleasant occasions may still arise.

3. Case Study

Culture Gate is a multidisciplinary multipurpose online participatory platform for cultural heritage. Koukopoulos and Koukopoulos (2016) give a thorough presentation of system architecture, modules, user roles and permitted operations. The system supports the collection of tangible or intangible cultural content, its digitisation and its digital preservation. In addition, the system permits user friendly content organisation and enables dissemination to an audience that shares a passion for cultural heritage. The platform aspires to become a place of gathering and communication among people with common interests and in the long-term an online community for cultural heritage.

3.a System functionality

The digital content of the platform is generated and contributed solely by the users. Each user contributes small portions of information, potentially resulting in vast amounts of data. Users can be experts in cultural heritage (researchers, scholars, museum curators etc.) or amateur enthusiasts. Each user retains full ownership over her/his contributions and responsibility over the uploaded content. Users are encouraged to upload content of cultural significance and, if necessary, state their sources explicitly. In order for a user to make a contribution, membership in *Culture Gate* is required. When a user registers an account, the role of “contributor” is assigned automatically. The registration procedure is vital for security, privacy and personalisation purposes. Contributors are allowed to manage (edit/delete) their content without explicit permission by the system.

Cultural content refers to any information that bears an element of cultural heritage. The platform stores and organises cultural content in items. Every cultural item refers to a piece of tangible or intangible cultural information. A cultural item could be a review of an archaeological find or a 3D representation of an excavation site, a picture and a description of an exhibit in an archaeological museum, a recorded performance in an ancient theatre or a discussion between archaeologists about recent research results. The platform collects both tangible and intangible cultural content. Tangible cultural content could be an ancient vessel located in an archaeological museum or an archaeological site, where a visitor takes a picture or captures video, writes an annotation and publishes the content to the platform. Intangible cultural content could be a real-time event like a theatrical display of Greek tragedy, where a spectator records the performance on a mobile device. *Culture Gate* presents cultural information referring to major cultural disciplines (i.e. Archaeology, Architecture, Museology, Music, Theatre, Cinema, Folklore, History, Libraries, Literature, Serious Games and Visual Arts). A user can search for archaeological information in Italy or architectural information in Europe.

The platform supports the digitisation and preservation of cultural content. The two main modules used for data collection are the *Online Web Portal* (OWP) and the dedicated mobile application *Culture Gate Collector* (CGC). OWP provides an easy-to-use online form guiding users to upload their contributions easily and as rich in data as possible. CGC is an application that can be installed in the mobile device of a user. CGC is intended to be used when the user is at an uncharted outdoor location like an excavation site (field functionality), a charted outdoor location like a city street (street functionality) or an indoor location (like an archaeological museum indoor functionality). CGC captures cultural content in the form of video, audio or image file, adds an annotation like a title, description, cultural discipline and sends it to the system web server.

Contributed content is stored in isolated modules, thus increasing the level of security. Each contribution is considered as a cultural item and it is associated with a database record and a directory in the file system. The item's directory stores audio, video, image and multimedia files of the most common types and formats (mp3, mp4, jpg, png, tiff, ogg etc.). The item's database record contains a series of metadata fields. Basic thematic metadata (i.e. title, description, corresponding cultural disciplines and keywords) are content-based attributes. Geographical data (i.e. geographical coordinates, address, city and country), contact details (i.e. website, email and phone number) and language are context-based attributes. The item's author details, his/her visibility (private or public) and classification as expert are model-based attributes.

Cultural items are organised and displayed to the public in friendly, interactive and easy-to-use styles. *Cultural map* is a geographical map that represents cultural items as pins of distinct colours and icons (Fig.1).

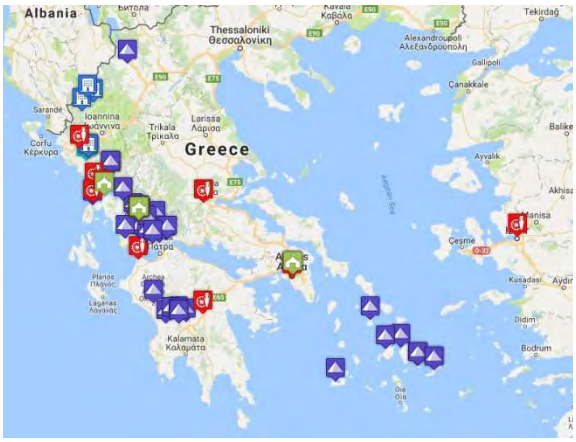

Figure 1 Culture Gate - Cultural Map.

Items that correspond to the same discipline bear the same marker colour and icon. This distinction allows users to detect items of the desired discipline easily. When a pin is clicked, a modal window pops up displaying the title, a featured image and brief information (Fig. 2).

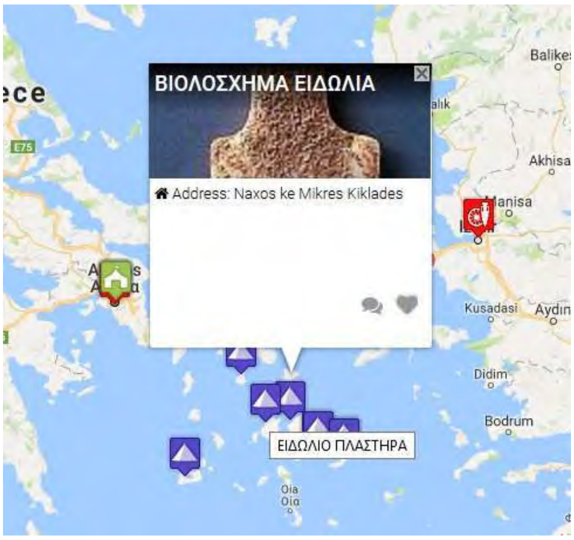

Figure 2 The user clicks on a pin.

More information about a particular item can be reached by clicking on the title or image that redirects to a dedicated web page (Fig. 3). The page contains a more thorough presentation of the item including its description, its contributor, evidence concerning its authoring by an expert or geographical address.

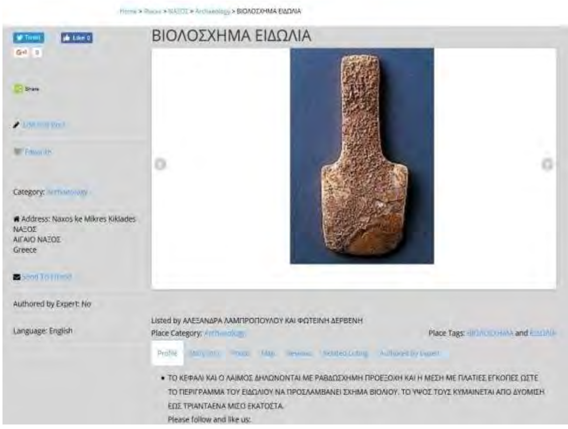

Figure 3 Dedicated webpage of a cultural item.

Cultural items can also be displayed in a list per discipline (Fig. 4). Users are able to search content per title, keywords, discipline, location and current location. Searching is performed variably. A user can search content in a certain location by inserting the appropriate search term like "Rome" or "Moscow". Alternatively, the user can search for nearby cultural items by clicking on the "Near Me" button. Thematic searches employ keywords (e.g. "Kazantzakis" and "Plato") or classification by discipline. *Cultural map* contains an interactive search box where users can insert content-based criteria (keywords, title, discipline) and filter content on the map directly (Fig. 5).

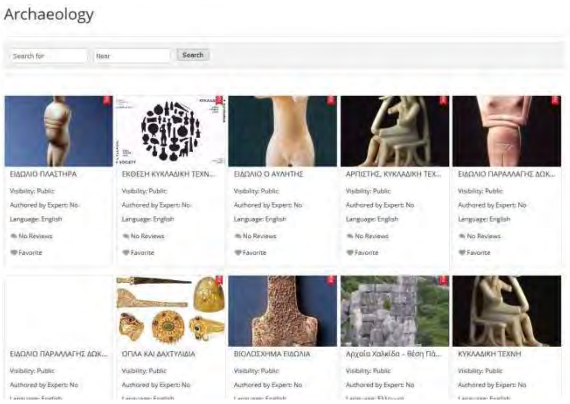

Figure 4 Archaeological cultural items list.

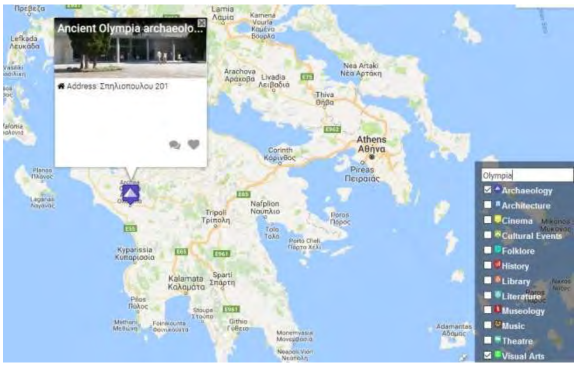

Figure 5 Direct filtering by keyword (Olympia) and by discipline (Archaeology).

The system supports a second mobile application for viewing nearby cultural content named *Culture Gate Guide* (CGG). CGG is used to display cultural items that are within a certain distance from the current position of the user (Fig. 6). Cultural items appear as pins on the map and the application provides directions. CGG offers guiding services when the user reaches the desired location.

3.b Additional features

Designing and implementing a creative dissemination plan in order to attract visitors is vital for public platforms. A platform is successful when users spend adequate time using it. *Culture Gate* uses several services to attract users and keep them in the system. A calendar of cultural events demonstrates events of cultural interest that take place near a user's residence (Fig. 7). A discussion forum engages users in conversations around cultural heritage issues. The use of discussion forums for enhancing user engagement is studied in various works in the field of public archaeology and in general (McDavid 2002b, Morales-Ramirez 2013, Redmayne & Woodward 2013, Rinner & Bird 2009, Seitsonen 2017, Vassileva 2012). Several evaluation attempts have proven the strength of this feature (McDavid 2002b, Rinner & Bird 2009). 3D representations of cultural items provide rare visual experience. Timelapse videos help users visualise how a cultural monument or site changes over time and serious games provide fun experience that educates younger and older individuals. All the above services require constant updates to maintain cutting edge aptitude and keep the audience interested. As a part of the dissemination strategy, the platform gives the opportunity to artists and experts to present their creations like smartphone applications, serious games, timelapse videos and 3D representations to the audience of *Culture Gate*. On one hand this feature helps attract more visitors to the platform, and on the other, it helps individual artists and experts reach a targeted audience of cultural heritage enthusiasts.

Figure 6 Culture Gate Guide.

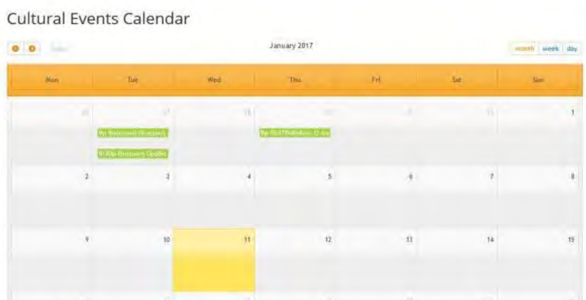

Figure 7 Calendar of Cultural Events.

3.c Noise detection and privacy

Culture Gate deals with the inevitable "noise" produced by its participatory nature via moderation (mandatory) and authoring (optional) of the uploaded content. Noise filtering takes place in two stages. Each new contribution is marked by the system as "draft". Moderators (i.e. registered users of the platform chosen by the system administrator) have elevated rights to access unpublished contributions and check the content for violations (i.e. content not related to cultural heritage or containing offensive declarations or including no mention of relevant sources). If no violation occurs, moderators publish content as "Not Authored by an Expert". On a second stage, the authoring procedure is initialised after the explicit request contributor. The system chooses an auditor randomly from a pool of registered users that are well-known professionals of a certain cultural discipline. The chosen auditor checks the content and suggests necessary modifications. The system receives the modifications and informs the contributor. If the contributor wants the content to be marked as "Authored by an Expert", suggested modifications are mandatory to implement. Contributions, which have been checked by an auditor, gain additional reputation.

Privacy is a very important issue when experts are urged to use an online system for uploading a part of their published or unpublished work. *Culture Gate* supports the formation of private groups and the uploading of private information. Private groups consist of a group leader (the user who asked for the formation of the private group) and a number of registered users as members of the group. All group members can upload and share information which is not visible by users outside the private group. The offered privacy solution permits the isolation of a special interest user group without requiring the establishment of privacy infrastructures like intra-sites (Forte & Lercari 2015). In this regard, *Culture Gate* does not target a formal cultural documentation mechanism, but a way to effectively disseminate cultural heritage content to the broader public. With respect to research groups, the platform encourages initial communication and data exchange. However, contributions can also be strictly private (i.e. only the contributor can access the content that she/he uploaded).

3.d Usage Scenarios for Archaeology

In order to demonstrate platform usability and usefulness for various stakeholders, we present a series of usage scenarios that may occur in real life situations.

Scenario 1 – A user contributes archaeological information requesting authoring.

A registered user wants to upload cultural content of archaeological interest. In particular, the user wants to inform the public about findings that were discovered at the excavation site of Plevrona near Mesolongi in Western Greece. The user requests content authoring by an expert in order to avoid false statements and gain in reputation. System moderators that manage uploaded content choose an auditor for the Archaeology discipline randomly. The auditor is notified to check content for accuracy. The auditor reviews the content and sends the necessary modifications to the system. Moderators receive auditor response and inform the original contributor. The contributor makes the appropriate modifications and publishes the authored content (Fig. 8).

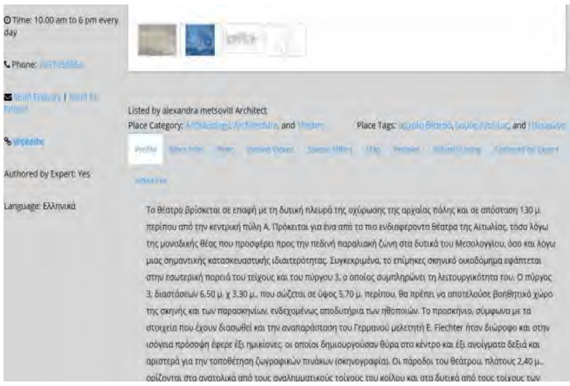

Figure 8 Authored contribution.

Scenario 2 – A user searches for nearby archaeological information using CGG.

An individual walks in the streets of Rome and wishes to find out the nearest archaeological monument. Using CGG on a tablet the user's geographical position is identified and cultural items within a user-determined distance are retrieved and displayed on a geographical map. The nearest item is highlighted and an information window appears. The user reads about the item and asks for directions to reach that location. Upon arrival at the desired location, the relevant audio guide is initiated by the CGG.

Scenario 3 – School Teacher visits an Archaeological site with students

A school teacher wants to guide children in a nearby archaeological site. Students are asked to download and install CGC on their smartphones and register to *Culture Gate*. While on location, students are asked to capture audio-visual content about the site's monuments. Students record images and videos and upload them to *Culture Gate* with annotations. Before the visit, the teacher has communicated with *Culture Gate's* moderators and formulated a private group containing her/himself as a group leader and students as members. All uploaded information from the visit becomes available solely within the private group. Later in classroom, a discussion is conducted among students and the teacher. Students state why they captured each digital document and the teacher corrects inaccurate annotations. Finally, the teacher makes the collected material public.

Scenario 4 – Professional guide accompanies a group of tourists in an ancient theatre

A professional guide who organises guided tours to the ancient theatre of Oiniades, in Western Greece, has joined *Culture Gate* and regularly uploads practical and historical information with rich multimedia content about the ancient monument in order to attract clients. Sometimes tours are scheduled to coincide with events, such as an ancient comedy performance. New clients accessing the relevant items are intrigued by the guide's approach and decide to use her/his services.

Scenario 5 – Triggering a forum discussion about archaeology

When a contribution is made about an archaeological topic requesting expert authoring, the auditor can create a relevant topic in the discussion forum. The auditor can invite other auditors of archaeological contributions to participate in the debate actively.

Scenario 6 – Archaeologist at an excavation site makes a discovery

A team of archaeologists is working separately at the excavation site and at the lab or some other distanced research facility. All team members are registered users of *Culture Gate* and they have formed a private group to exchange information. A team member, who works at the site, uses the CGC field functionality (Fig. 9) to capture an image of a new archaeological find and immediately sends the content to the private group. Colleagues at the research facility view the retrieved find and return their assessment to their remote colleagues.

Figure 9 CGC field functionality screen.

Conclusions

Active participation of a vast and heterogeneous group of individuals in cultural data collection and digitisation is an extremely promising idea. The success of modern platforms like *Facebook* and *YouTube*, where content is generated by billions of users, has proven the technical feasibility of such systems. Even though the expansion of user participation in the cultural heritage domain seems to be natural and obvious, we must not forget that social networking and cultural heritage are two very dissimilar fields. User-generated cultural content is not the same as social content, since matters of quality and intellectual property rights arise. A platform that presents and disseminates cultural content should contain qualitative restrictions, increasing the burden of filtering user-generated content produced on a daily basis and the potential financial cost of filtering and auditing mechanisms. In addition, cultural heritage platforms address a significantly smaller audience, which needs to be motivated to contribute cultural content to be directly publicly available.

Trying to investigate the feasibility of participatory digital platforms in cultural heritage, we used as a case study a new participatory digital system, *Culture Gate*. We implemented several usage scenarios targeting the archaeological domain from excavation to preservation, dissemination and educational actions. Such scenarios attempt to predict the usability of the system in real-life situations. Services like CGC permit the direct exchange of collected information, while CGG enables personalised visitor guiding in isolated archaeological sites. Besides, discussion forum and calendar system features allow communication and knowledge exchange among users. The entire set of solutions presented aim to enhance the social impact of the system to all potential users, professionals, visitors, educators, students and local communities.

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