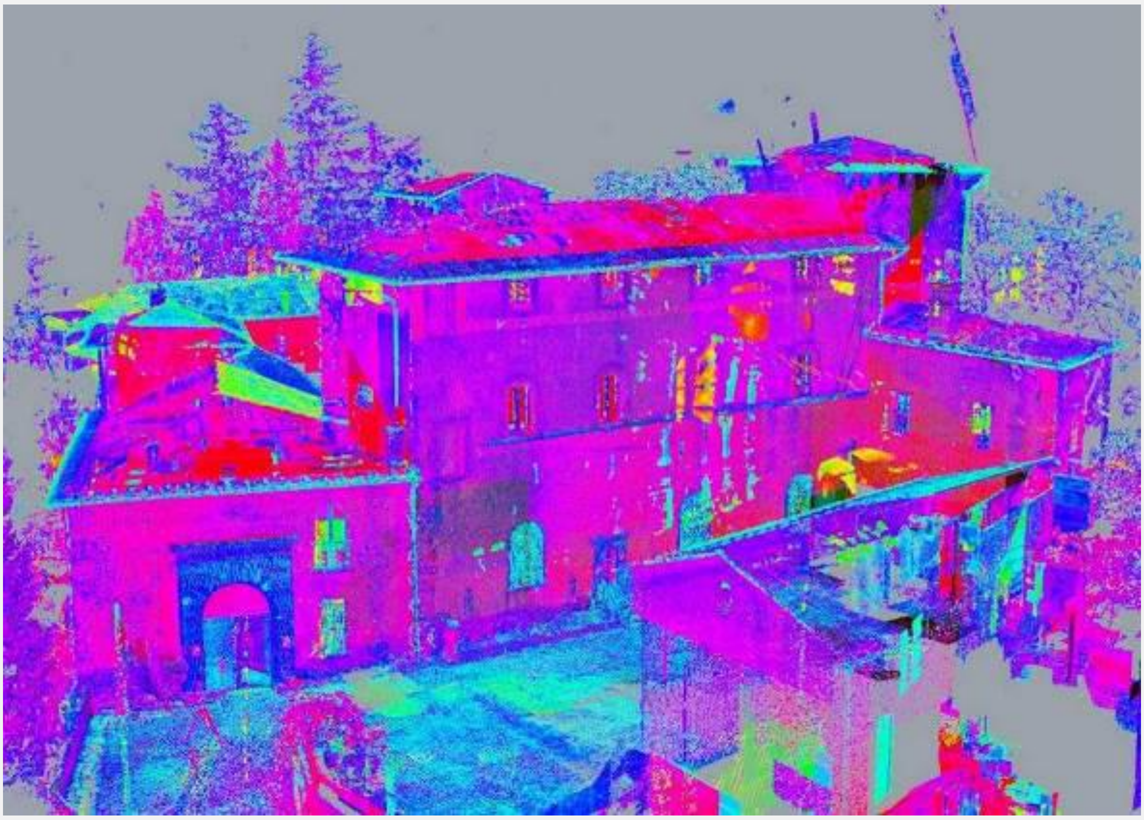
CAA-GR 2018

Spreading Excellence in Computer Applications for Archaeology and Cultural Heritage

Proceedings of the 3rd CAA-GR Conference
18-20 June 2018, Limassol, Cyprus

Edited by
Phaedon Kyriakidis · Athos Agapiou · Vasiliki Lysandrou



Limassol-Cyprus, 2019

3rd Computer Applications and Quantitative Methods in Archaeology (CAA-GR) Conference, 2018

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Front page picture: Castel Masegra Sondrio (Lombardy, Italy). A courtesy of Luigi Barazzetti (CAA Gr 2018 Conference best paper award)

Preface

CAA (Computer Applications and Quantitative Methods in Archaeology) is the premier international conference for all aspects of computing, quantitative methods and digital applications in Archaeology. With a history going back to 1972, CAA encourages participation from scholars, specialists and experts in the fields of archaeology, history, cultural heritage, digital scholarship, GIS, mathematics, semantic web, informatics and members of other disciplines that complement and extend the interests of CAA.

The Greek chapter of CAA International (CAA-GR) was established in 2012, in order to develop a forum for discussing practical, theoretical and methodological issues involved in the increasing number of computer applications in Greek archaeological and cultural heritage contexts and sharing the results of related research. CAA-GR aims to encourage communication between different disciplines, to provide a survey of present work in the field, to stimulate discussion and further develop relevant research areas. For these reasons, it welcomes archaeologists with expertise from a variety of disciplines in the field of social sciences, life sciences, engineering and arts, actively involved in computer applications in the cultural heritage domain, conservators, mathematicians and computer scientists.

This volume contains the proceedings of the 3rd CAA-GR conference, which was held at the Cyprus University of Technology, in Limassol, Cyprus, from Tuesday 19th to Wednesday 20th June 2018. The main venue preceded a workshop entitled *3D Data Processing for Built Heritage and Archaeology: Laser Scanner and Other Low Cost Solutions* (Instructors: Luigi Barazzetti, Assistant Professor, Dept. ABC – Politecnico di Milano and Dr. Riccardo Valente, Politecnico di Milano), carried out on Monday, 18th June 2018 in Limassol, Cyprus.

The proceedings are divided into six thematic sessions, based on the content of the submitted papers, containing a total of 18 contributions in Greek or English, which have been reviewed by the conference's scientific committee. The sessions are as follows: (1) Field Prospection and Recording in Support of Archaeological Excavation and Research; (2) Geospatial Technologies for Mapping and Monitoring Cultural Heritage; (3) Cultural Heritage Databases; (4) 3D Reconstruction and Modeling; (5) Modern Technologies for Cultural Heritage Representation and Promotion; (6) Statistical/Agent-Based Modeling.

We wish to conclude this preface by thanking the CAA-GR Board, the Cyprus University of Technology (CUT) for hosting the event and all of the CUT's students who helped before, during and after the conference. Special thanks are extended to the scientific committee who kindly accepted to review the submitted papers.

P. Kyriakidis, A. Agapiou, V. Lysandrou

Limassol, Cyprus,

March 2019

Organisation

The 3rd CAA-GR Conference was organised by

- The Cyprus University of Technology (CUT), Department of Civil Engineering and Geomatics
- The University of Cyprus (UCY), Department of History and Archaeology

With the support of

- Horizon 2020 Spreading Excellence and Widening Participation, "Teaming for Excellence" Phase 1, *MedSTACH* project (www.medstach.eu)

Labelled as

- European Year of Cultural Heritage (EYCH) 2018 initiative

European Year of Cultural Heritage 2018 (EYCH) The CAA-Gr 2018 conference has been awarded the European Year of Cultural Heritage 2018 (EYCH) label. The decision of the EYCH 2018 label award was based on the fact that the CAA-Gr 2018 conference can contribute to the achievement of one or more of the general and specific objectives of the European Year of Cultural Heritage 2018, as endorsed by the European Parliament and the Council of the EU in Article 2 of the legal decision calling for the EYCH. The label was awarded by the Department of Antiquities of Cyprus.

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Welcome Speech

Prof. Phaedon Kyriakidis, Chair of the Local Organising Committee

Honorable Rector of the Cyprus University of Technology, dear participants, friends and colleagues

On behalf of the local organizing committee, it is a great honor and pleasure to welcome you at the 3rd CAA-GR conference here in Limassol, Cyprus, at the premises of the Cyprus University of Technology (CUT). We are proud that, in the spirit of CAA, the 3rd CAA-GR conference is jointly organized by the Department of Civil Engineering and Geomatics of CUT and the Archaeological Research Unit (ARU) of the University of Cyprus (UCY).

The Department of Civil Engineering and Geomatics includes 20 permanent staff and several research associates, and its facilities - being part of those of CUT - lie at the heart of the old town of Limassol. At the undergraduate level, the Department offers two distinct degrees, one in Civil Engineering, and one in Surveying Engineering and Geomatics. At the post-graduate level, the Department offers two MSc programs, one in Civil Engineering and Sustainable Design, and one in Geoinformatics and Geospatial Technologies. A PhD-level program is also in place, hosting several doctoral candidates in a variety of fields, ranging from earthquake engineering and structural analysis to geodesy, photogrammetry, remote sensing, GIS and other facets of geoinformatics. Among the Department's recent research highlights are the H2020 Teaming for Excellence Phase 1 projects – MedSTACH and Excelsior – that both attained highest scores among 208 proposals from coordinating institutions based in the countries of "New Europe". The two proposals will be competing to secure funding up to 15 million euros each from the European Commission for a period of 7 years, with an additional equal amount of co-funding from the government of Cyprus for a period of 15 years.

The Computer Applications and Quantitative Methods in Archaeology (CAA) is an international organization that brings together a range of scholars, specialists and experts in the fields of archaeology, history, cultural heritage, digital scholarship, GIS, mathematics, semantic web and informatics with an interest in interdisciplinary collaborations. Its aims are to encourage communication between these disciplines, to provide a survey of present work in the field, and to stimulate discussions and networking.

The Greek chapter of the international non-profit organization "Computer Applications and Quantitative Methods in Archaeology» (CAA-GR) was established in 2012. Members of CAA-GR are scientists from the fields of archeology, social sciences, life sciences, arts, mathematics, information technology, engineers and scientists in all fields of cultural heritage.

As the objectives of CAA-GR are fully aligned with those of the H2020 Teaming for Excellence Phase 1 project with acronym MedSTACH, aiming to design a Cyprus-based, Eastern Mediterranean Science and Technology Center of Excellence for Archaeology and Cultural Heritage (for which I will be briefing you shortly), it is only natural that the 3rd CAA-GR conference is also supported by the MedSTACH project.

In terms of the actual conference, we are excited to have two days of very interesting presentations -- on top of the very successful workshop given yesterday on 3D data processing for built heritage and archaeology: laser scanner and other low-cost solutions -- from a diverse set of authors from 15 countries (apart from Greece and Cyprus).

In terms of thematic content, the 3rd CAA-GR conference includes 40 contributions, arranged in 6 (+1 poster) sessions, spread out in 2 days:

- Field prospection and recording methods for excavation and laboratory work,
- Use of geospatial technologies and remote sensing for mapping the cultural landscape
- Modeling, management and semantics of cultural data
- 3D reconstruction, modeling and visualization (Part I)
- Poster Session
- 3D reconstruction, modeling and visualization (Part II)
- Application of non-destructive techniques within Cultural Heritage

Lunch is provided at the conference venue, whereas dinner is on an individual basis.

In closing, we would like to thank the board of CAA-GR for entrusting the organization of the 3rd CAA-GR conference to the Department of Civil Engineering and Geomatics of the Cyprus University of Technology and to the Archaeological Research Unit of the University of Cyprus. We would also like to thank the Department of Antiquities of Cyprus for granting free passes to all cultural heritage sites in Limassol for the conference days, and for bestowing the 2018 European Year of Cultural Heritage label to this event. We wholeheartedly thank Prof. Maria Iacovou (University of Cyprus) for agreeing to give the plenary speech of the conference, as well as Prof. Luigi Barazzetti and Dr Riccardo Valente (Politecnico di Milano) for coordinating the Monday workshop.

Last, we extend our sincere thanks to Smart Events for providing invaluable organizational support, as well as all those who have helped on the ground to make this event a scientifically rewarding and socially enjoyable experience for its participants.

Session 1

Field Prospection and Recording in

support of archaeological excavation and research

ΥΠΕΔΑΦΕΙΕΣ ΕΙΚΟΝΕΣ ΑΠΟ ΤΟ ΠΟΛΙΤΙΣΜΙΚΟ ΤΟΠΙΟ ΤΗΣ ΕΙΔΟΜΕΝΗΣ, ΚΙΛΚΙΣ, ΒΟΡΕΙΑ ΕΛΛΑΔΑ
UNDERGROUND IMAGES FROM THE CULTURAL LANDSCAPE OF IDOMENI, KILKIS, NORTHERN GREECE

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Περίληψη

Πρόσφατη ανασκαφική έρευνα σωστικού χαρακτήρα που διενεργήθηκε το 2015 από την Εφορεία Αρχαιοτήτων Κιλκίς σε αγροτική περιοχή στα νότια του οικισμού της Ειδομένης, σε συνέχεια ανάλογης παλαιότερης (2007) από την ΙΣΤ΄ Εφορεία Προϊστορικών και Κλασικών Αρχαιοτήτων, αποκάλυψε ορύγματα τα οποία σχετίζονται με νεολιθικό οικισμό, από τους ελάχιστους εντοπισμένους στην ευρύτερη περιοχή της κοιλάδας του Αξιού και του μοναδικού που έχει ερευνηθεί ανασκαφικά, καθώς επίσης, και ταφικά κατάλοιπα από νεκροταφείο της Μέσης Βυζαντινής περιόδου. Σε μία προσπάθεια να διερευνηθεί ο χώρος του οικισμού, του νεκροταφείου αλλά και της ευρύτερης περιοχής, διεξήχθησαν γεωφυσικές διασκοπήσεις με στόχο τη χαρτογράφηση του πολιτισμικού τοπίου της περιοχής.

Οι ενδείξεις που προέκυψαν από τα αποτελέσματα της συνδυαστικής εφαρμογής των μαγνητικών, ηλεκτρομαγνητικών, και ηλεκτρικών διασκοπήσεων και του γεωραντάρ υποδεικνύουν ότι η νεολιθική εγκατάσταση και ενδεχομένως το βυζαντινό νεκροταφείο περιορίζονταν στην πλαγιά μικρού χαμηλού γηλόφου στο αγρόκτημα Ειδομένης, στον οποίο διενεργούνται οι ανασκαφές. Στις γύρω περιοχές, όπου υπήρχε επιφανειακά μεγάλη πυκνότητα και διασπορά τροχήλατης κυρίως κεραμικής ανιχνεύθηκαν στο υπέδαφος κατάλοιπα νεότερων ιστορικών χρόνων.

Οι γεωφυσικές και ανασκαφικές έρευνες είχαν ως αποτέλεσμα την σκιαγράφηση του πολιτισμικού τοπίου της περιοχής και των μετασχηματισμών του από διαχρονική σκοπιά.

Abstract

Recent excavations (2015), by the Ephorate of Antiquities at Kilkis, following initial exploration in 2007 by the IST' Ephorate of Prehistoric and Classical Antiquities, to the south of the modern village of Idomeni, Kilkis, Northern Greece, revealed a cemetery of the Middle Byzantine Period and a number of pit formations of a Neolithic settlement, one of the few known in the region and the only one under systematic research. Based on this, a geophysical project has been organized in an attempt to explore the wider area of the cemetery/settlement and map the cultural landscape of the surroundings.

The indications that have emerged from the results of the combined application of magnetic, electromagnetic, electrical and GPR surveys suggest that the Neolithic habitation and possibly the Byzantine cemetery were limited to the hill on which excavations have been carried out. In the surrounding areas where there was a high density of ceramic fragments, residues most probably of the more recent past have been detected.

The geophysical and excavation research have given results that delineate the cultural landscape and its transformations from a diachronic perspective.

Λέξεις Κλειδιά/Keywords: Idomeni, Kilkis, Neolithic settlement, Middle Byzantine Period, Geophysics.

1. Εισαγωγή

Η αρχαιολογική θέση της Ειδομένης βρίσκεται περίπου 2χλμ. ΝΑ του ομώνυμου χωριού, στα βόρεια της Περιφερειακής Ενότητας (ΠΕ) Κιλκίς, πολύ κοντά στα σύνορα με τη Βόρεια Μακεδονία, και εντοπίστηκε στα τέλη του 2006 κατά τη διάρκεια κατασκευής του έργου «Γέφυρα Αξιού με τις προσβάσεις προς Ειδομένη και Ευζώνους». Η θέση ήρθε στο φως από τη χρήση παρακείμενου αγρού ως δανειοθαλάμου απόληψης αδρανών.
Η ανασκαφική σωστικού χαρακτήρα έρευνα που έχει διεξαχθεί μέχρι σήμερα σε δύο φάσεις (βλ. παρακάτω) έχει προσδιορίσει την ύπαρξη καταλοίπων ανθρώπινης δραστηριότητας της νεολιθικής εποχής και της Μέσης βυζαντινής περιόδου.

Η παρουσία νεολιθικής οικιστικής εγκατάστασης στοιχειοθετείται από την αποκάλυψη συμπλεγμάτων από αβαθή ορύγματα (λάκκοι), διανοιγμένα στο φυσικό γεωλογικό υπόβαθρο. Η περιεχόμενη σε αυτά κεραμική ανάγει την εγκατάσταση στη Νεότερη και Τελική Νεολιθική.

Η προϊστορική θέση απλώνεται πάνω σε χαμηλό γήλοφο. Αρχικά, διερευνήθηκε το 2007 από την ΙΣΤ΄ Εφορεία Προϊστορικών και Κλασικών Αρχαιοτήτων (Βάλλα & Μίχα 2010, Βάλλα 2014) το δυτικό πλάτωμα (τομέας Α) (Εικόνα 1) και αποκαλύφθηκαν 13 δομές λάκκων. Επιπλέον, κατά την πρώτη εκείνη ερευνητική περίοδο αποκαλύφθηκαν διάσπαρτες ταφές που εντάσσονται σε νεκροταφείο μεσοβυζαντινών χρόνων (10ος – 12ος αι. μ.Χ.), ιδρυμένο μερικώς στις επιχώσεις του προϊστορικού οικισμού, καθώς και λιθόκτιστα θεμέλια τοίχων, οικιστικά δηλαδή κατάλοιπα πιθανόν σύγχρονα με το νεκροταφείο.

Ανάλογη εικόνα προκύπτει και από τη συνέχιση της ανασκαφικής έρευνας οκτώ χρόνια αργότερα, το 2015, από την Εφορεία Αρχαιοτήτων Κιλκίς με επίκεντρο πλέον το ανατολικό πλάτωμα του γηλόφου (τομέας Β) (Χατζητουλούσης υπό έκδοση). Σκοπός της νεότερης αυτής έρευνας ήταν ο προσδιορισμός της έκτασης, των ορίων και της χωροταξικής κατανομής των καταλοίπων και για τις δύο προαναφερθείσες πολιτισμικές περιόδους. Κατά τη δεύτερη φάση της έρευνας εντοπίστηκαν επτά ορύγματα της Νεολιθικής με ελλειψοειδή κάτοψη σε πυκνή διάταξη. Πιθανότατα ανήκαν σε ενιαίο οικιστικό σύνολο. Διερευνήθηκαν συστηματικά τα δύο από αυτά. Οι λακκοειδείς αυτές κατασκευές αποτελούν κατάλοιπα αντιπροσωπευτικά του τρόπου οικιστικής ανάπτυξης που παρουσιάζουν οι προϊστορικές εγκαταστάσεις της Νεότερης Νεολιθικής στον χώρο της Κεντρικής Μακεδονίας. Φαίνεται ότι εξυπηρετούσαν, ανάλογα με τις διαστάσεις και το σχήμα τους, ανάγκες αποθηκευτικές, απορριμματικές ή και στέγασης. Το 2015, αποκαλύφθηκε μία ακόμη μεσοβυζαντινή ταφή/ανακομιδή.

Ενδιαφέρον παρουσιάζει το γεγονός ότι από τη θέση συλλέχθηκαν κατά την ανασκαφή και δείγματα οπλικών εξαρτημάτων (π.χ. μολύβδινες σφαίρες, τμήμα οβίδας), που υποδηλώνουν χρήση της περιοχής ως πεδίου μάχης στους νεότερους χρόνους.
Η αρχαιολογική σημασία της θέσης έγκειται καταρχήν στο ότι συνδυάζει στις επιχώσεις της πληροφοριακό απόθεμα για τρεις διαφορετικές χρονοπολιτισμικές περιόδους: τη Νεότερη Νεολιθική, τη Μέση Βυζαντινή και το πρώτο ήμισυ του 20ού αι. Ο διαφορετικός μάλιστα τρόπος χρήσης του χώρου στους αιώνες τεκμηριώνει μετασχηματισμούς του πολιτισμικού αυτού τοπίου στην κοιλάδα του Αξιού ποταμού, το οποίο αποτέλεσε και συνεχίζει να αποτελεί κομβικό πέρασμα από το Βορρά στο Νότο και αντίστροφα.

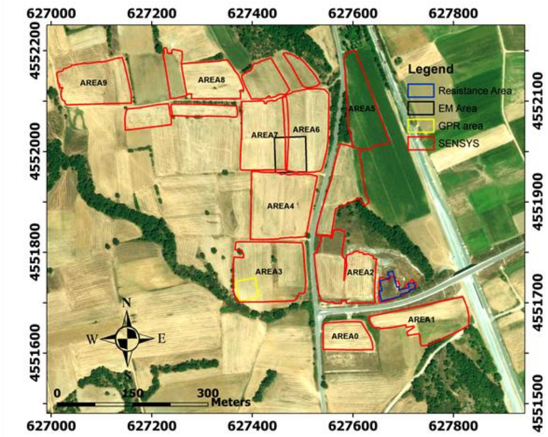
Εικόνα 1. Νεολιθικοί λάκκοι που είχαν αποκαλυφθεί κατά την ανασκαφή του 2007.

2. Οι Γεωφυσικές Έρευνες. Μεθοδολογία.

Με στόχο την διερεύνηση του ευρύτερου πολιτισμικού τοπίου της Ειδομένης από διαχρονική σκοπιά και με έμφαση στον προσδιορισμό των ορίων και τον εντοπισμό δομών του νεολιθικού οικισμού, οργανώθηκε, το 2017, συστηματική γεωφυσική έρευνα[1] η οποία επεκτάθηκε σε διάφορα τμήματα

[1] Το συνεργατικό πρόγραμμα της Εφορείας Αρχαιοτήτων Κιλκίς και του Ιδρύματος Τεχνολογίας και Έρευνας πραγματοποιήθηκε μέσω Προγραμματικής Σύμβασης Πολιτισμικής Ανάπτυξης και με χρηματοδότηση της

στον περίγυρο του ανασκαφικού χώρου που εμφάνιζαν επιφανειακά μεγάλη πυκνότητα κεραμικής (Εικόνα 2). Οι μετρήσεις πραγματοποιήθηκαν τον Δεκέμβριο του 2017 και διερευνήθηκε συνολική έκταση 142.270 τετραγωνικών μέτρων (14,23 εκτάρια). Κατά τη διάρκεια των γεωφυσικών ερευνών χρησιμοποιήθηκαν μαγνητικές, ηλεκτρικές και ηλεκτρομαγνητικές τεχνικές και η μέθοδος του γεωραντάρ. Ο συνδυασμός των τεχνικών βελτιστοποίησε τα αποτελέσματα της έρευνας. Θα πρέπει να σημειωθεί ότι όλες οι τεχνικές έδωσαν έμφαση στην λεπτομερή χαρτογράφηση του χώρου (δειγματοληψία 0.5-1μ. για τις ηλεκτρικές και ηλεκτρομαγνητικές διασκοπήσεις αντιστοίχως, 2,5εκ. κατά μήκος των οδεύσεων του γεωραντάρ απείχαν 50εκ. μεταξύ τους και 0.5x0.1μ. για την μαγνητική χαρτογράφηση).



Εικόνα 2. Δορυφορική εικόνα από το Google Earth της ευρύτερης περιοχής του αρχαιολογικού χώρου της Ειδομένης στην οποία έχουν αποτυπωθεί οι περιοχές που πραγματοποιήθηκαν οι γεωφυσικές διασκοπήσεις.

Η μέθοδος του γεωραντάρ έκανε χρήση του NOGGIN GPR Smart Cart Plus με κεραία των 250MHz (Εικόνα 3). Η κατακόρυφη δειγματοληψία ήταν της τάξης των 0.3-0.4ns και το βάθος διείσδυσης έφθασε τα 2-3μ. από την σημερινή επιφάνεια του εδάφους. Στις μαγνητικές διασκοπήσεις χρησιμοποιήθηκαν 2 μονάδες πολλαπλών μαγνητόμετρων Sensorik & Systemtechnologie (SENSYS) MX Compact. Κάθε σύστημα είχε εξοπλιστεί με οκτώ διαφορικά μαγνητόμετρα FGM600 και μία μονάδα GPS (rover) που συνεχώς επικοινωνούσε με ένα σταθμό βάσης (base) για την διόρθωση της θέσης και επίτευξης ακρίβειας μικρότερης από 1εκ. (Εικόνα 4). Οι ηλεκτρομαγνητικές διασκοπήσεις πραγματοποιήθηκαν με την χρήση του οργάνου CMD MiniExplorer (Εικόνα 5). Το συγκεκριμένο όργανο αποτελείται από τρία δίπολα που απέχουν 0.32μ., 0.71μ. και 1.18μ. μεταξύ τους. Τέλος, στις ηλεκτρικές διασκοπήσεις έγινε χρήση του οργάνου Geoscan Research Resistivity meter RM85 με διπλή διάταξη ηλεκτροδίων σε απόσταση 0.5μ.

Εικόνα 3. Το γεωραντάρ NOGGIN PLUS με τις κεραίες των 250 MHz.

Εικόνα 4. Συστήματα πολλαπλών μαγνητομέτρων SENSYS που χρησιμοποιήθηκαν στην Ειδομένη.

Εικόνα 5. Το όργανο CMD MiniExplorer που χρησιμοποιήθηκε κατά τις ηλεκτρομαγνητικές διασκοπήσεις.

Περιφέρειας Κεντρικής Μακεδονίας. Ευχαριστίες εκφράζονται στον Αντιπεριφερειάρχη Κιλκίς κ. Ανδρέα Βεργίδη και στην πρόεδρο της τοπικής κοινότητας Ειδομένης, κα. Ξανθίππη Σουπλή, για τη θερμή υποστήριξή τους, καθώς και στους ιδιοκτήτες των αγρών για την συγκατάθεσή τους να διεξαχθεί η έρευνα.

3. Αποτελέσματα των Γεωφυσικών Ερευνών

Οι γεωφυσικές έρευνες περιορίστηκαν στη χαρτογράφηση του υπεδάφους μέχρι ένα βάθος περίπου 1-2μ. μέσω των μαγνητικών, ηλεκτρικών, ηλεκτρομαγνητικών και GPR μετρήσεων. Αυτόνομα, κάθε μία από τις γεωφυσικές τεχνικές έδωσε διαφορετικές πληροφορίες για τα υπεδάφεια αρχιτεκτονικά χαρακτηριστικά ανάλογα με την μετρήσιμη ιδιότητα, ενώ η συνδυαστική εφαρμογή των διαφορετικών γεωφυσικών μεθόδων ενίσχυσε και επιβεβαίωσε συγκεκριμένες γεωφυσικές ανωμαλίες.

Για την καλύτερη ερμηνεία των γεωφυσικών ανωμαλιών και την συσχέτισή τους με την γεωμορφολογία της περιοχής, έγινε γεωαναφορά όλων των γεωφυσικών χαρτών στο τοπογραφικό σχέδιο των καννάβων και στην γεωαναφερμένη δορυφορική εικόνα της περιοχής από το Google Earth (μέσω του ArcGIS 10.4).

Στην Εικόνα 6 παρουσιάζεται το σύνολο των μαγνητικών μετρήσεων που διεξήχθησαν στον χώρο. Είναι φανερό ότι η περιοχή ενδιαφέροντος παρουσιάζει μεγάλη ανομοιογένεια σε σχέση με τα μαγνητικά σήματα που έχουν εγγραφεί.

Εικόνα 6. Αποτελέσματα των μαγνητικών μετρήσεων σε όλη την έκταση του χώρου που διερευνήθηκε γύρω από την περιοχή του Νεολιθικού οικισμού της Ειδομένης.

Υπάρχουν διάφορα είδη χαρακτηριστικών τα οποία εμφανίζονται σε διαφορετικά τμήματα του χάρτη των μαγνητικών αποτελεσμάτων. Τα χαρακτηριστικά αυτά διακρίνονται στις ακόλουθες κατηγορίες:

1) **Ισχυρές διπολικές μαγνητικές ανωμαλίες** οι οποίες οφείλονται σε μεταλλικά θραύσματα. Οι ανωμαλίες αυτές έχουν το χαρακτηριστικό ότι είναι μεγάλης μαγνητικές έντασης και διπολικού χαρακτήρα με προσανατολισμό Β-Ν, με τον αρνητικό πόλο (σκούρες αποχρώσεις) να βλέπει προς τον βορρά. Σε μεταλλικά αντικείμενα οφείλονται και κάποιες πολύ ισχυρές **μονοπολικές μαγνητικές ανωμαλίες**. Θα πρέπει να σημειωθεί ότι σε όλη την έκταση που διερευνήθηκε υπήρχε μεγάλος αριθμός από θραύσματα οβίδων και άλλων καταλοίπων από το πεδίο μάχης του περασμένου αιώνα (ίσως στον Α΄ και Β΄ Παγκόσμιο Πόλεμο).

2) **Διπολικές μαγνητικές ανωμαλίες μέσης ή ασθενούς έντασης**, κυρίως προς τα ανατολικά της AREA 2, εκεί δηλαδή που έχουν διενεργηθεί οι προηγούμενες ανασκαφές και είναι το επίκεντρο του Νεολιθικού οικισμού. Οι ανωμαλίες αυτές, που είναι χαρακτηριστικές του συγκεκριμένου χώρου, ενδέχεται να σχετίζονται με κατάλοιπα του νεολιθικού οικισμού ή ταφών της Βυζαντινής περιόδου.

3) **Γραμμικές εκτεταμένες ανωμαλίες** που φαίνεται να οφείλονται σε παλαιότερα όρια των ιδιοκτησιών, μονοπάτια, ίχνη από αρδευτικά κανάλια κ.ά. Σε πολλές περιπτώσεις οι ανωμαλίες αυτές εμφανίζονται σε παλαιότερες φωτογραφίες από το Google Earth.

4) **Συγκεντρώσεις εκτεταμένων ισχυρών μαγνητικών ανωμαλιών** που έχουν σαφή οριοθέτηση αλλά δεν επιτρέπουν κάποια λεπτομερή ερμηνεία λόγω της ασάφειας που υπάρχει στην εσωτερική τους δομή. Αν και σε μερικές περιπτώσεις διακρίνονται κάποια γραμμικά χαρακτηριστικά στο εσωτερικό τους, δεν είναι εφικτό να προχωρήσουμε σε μια ερμηνεία της εσωτερικής κατανομής των στοιχείων που εντάσσονται σε αυτά. Ενδεχομένως να πρόκειται για κατάλοιπα οικισμών του σχετικά πρόσφατου παρελθόντος (π.χ. 19ος, 20ος αι.), οι οποίοι εγκαταλείφθηκαν και ισοπεδώθηκαν για να δοθούν στην συνέχεια για καλλιέργεια, όπως συνέβη με τις γειτονικές ιδιοκτησίες. Το στρώμα καταστροφής είναι μεν ανιχνεύσιμο από τις μαγνητικές τεχνικές, αλλά έχει απωλέσει κάθε πληροφορία της εσωτερικής κατανομής των κτηρίων και οργάνωσης του χώρου.

Για παράδειγμα, το χωριό της Ειδομένης κάηκε, σύμφωνα με τον Carnegie (1914), από τον ελληνικό στρατό στον Β΄ Βαλκανικό πόλεμο, ενώ αργότερα έγινε εγκατάσταση 173 χριστιανών προσφύγων /49 οικογενειών [ΕΑΠ 1928]. Το ίδιο έγινε και με άλλα χωριά που βρίσκονταν στην περιοχή, όπως το Δογάνη (Σλοπ) και το Μουίν. Ενδεχομένως επίσης, χωριά τα οποία κάηκαν και καταστράφηκαν ολοσχερώς στις πολεμικές συρράξεις να μετακινήθηκαν σε άλλες τοποθεσίες.

Θα μπορούσε λοιπόν, να υποθέσει κανείς ότι πολλές από τις συγκεντρώσεις εκτεταμένων ισχυρών μαγνητικών ανωμαλιών που έχουν χαρτογραφηθεί στις διάφορες περιοχές της έρευνας να οφείλονται ενδεχομένως σε κατάλοιπα κατεστραμμένων οικισμών.

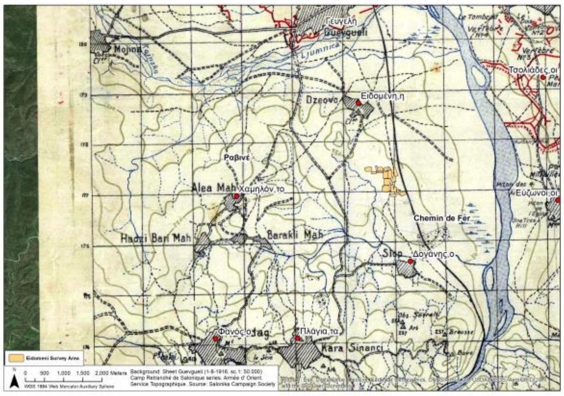
Ωστόσο, σύμφωνα με την ανάλυση[2] των χωρικών δεδομένων από τους χάρτες του Α΄ Παγκοσμίου Πολέμου της Salonika Campaign Society και του Αρχείου Χαρτογραφικής Κληρονομιάς (οι οποίοι παρουσιάζουν την εξέλιξη του στρατιωτικού τοπίου στην ευρύτερη περιοχή γύρω από αυτήν της γεωφυσικής έρευνας) δεν προκύπτει οικιστική δραστηριότητα στην περιοχή της γεωφυσικής έρευνας.

Παρατηρείται επίσης, ότι η θέση της εγκατάστασης του Σεχόβου των αρχών του 20ου αιώνα και του Α΄ Παγκοσμίου Πολέμου συμπίπτει με την τοποθεσία της σημερινής Ειδομένης, χωρίς να υπάρχει επίσης, και καμία αρχειακή αναφορά σε μετατόπιση του οικισμού κατά τη διάρκεια της ιστορίας του (η πρωιμότερη αρχειακή αναφορά καταγράφεται στα 1568-1569), ενώ και όλοι οι γειτονικοί οικισμοί τοποθετούνται αντίστοιχα στη σημερινή τους θέση.

Επομένως, είναι πολύ δύσκολο να υποστηρίξει κανείς την πιθανότητα ύπαρξης στην περιοχή της γεωφυσικής έρευνας είτε του οικισμού της Ειδομένης (σε κάποια παλιότερη φάση κατοίκησης) είτε κάποιας άλλης μουσουλμανικής κατοίκησης (μαχαλάς;) κατά την Οθωμανική περίοδο.

Για τον λόγο αυτό, και λαμβάνοντας υπόψη τα ισχύοντα έως σήμερα ανασκαφικά δεδομένα, σύμφωνα με τα οποία τεκμηριώνεται η αμέσως προγενέστερη των μέσων του 16ου αιώνα (οπότε καταγράφεται η ίδρυση του Σεχόβου, όπως σημειώνεται λίγο πιο πάνω), χρήση του χώρου, δηλαδή η Μέση Βυζαντινή περίοδος, αλλά όχι και η ύστερη Βυζαντινή ή η μεταγενέστερη Οθωμανική, μπορούμε να θεωρήσουμε ότι τα οικιστικά κατάλοιπα που υποδηλώνονται από την παρουσία των καμένων πηλών ή (και) πλίνθων είναι πιθανό να ανάγονται επίσης στην Μεσοβυζαντινή αυτή περίοδο.

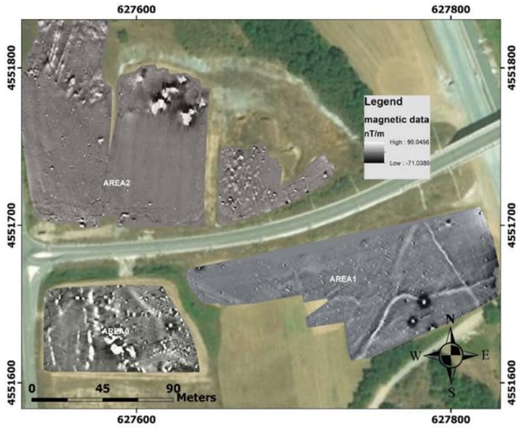
Με άλλα λόγια, φαίνεται αρκετά πιθανή η υπόθεση ότι τα συγκεκριμένα κατάλοιπα που ανιχνεύτηκαν από την γεωφυσική διασκόπηση του υπεδάφους να στοιχειοθετούν την παρουσία μιας οικιστικής εγκατάστασης, που θα είχε αναπτυχθεί σε σχετικά μικρή απόσταση από το ανασκαφικά εντοπισμένο (το 2007 και το 2015) μεσοβυζαντινό νεκροταφείο και κατά την ίδια περίοδο με εκείνο. Η χωρική αλλά και η χρονική συνάφεια των δύο αυτών χώρων, του ταφικού και του οικιστικού, αποτυπώνονται στον χάρτη της Εικόνας 7.



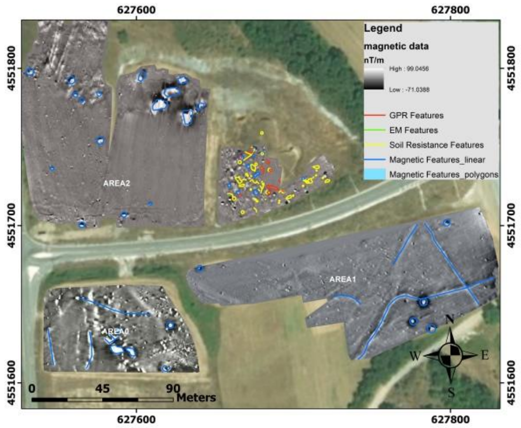
Εικόνα 7. Χαρτογράφηση του τοπίου γύρω από την περιοχή της γεωφυσικής έρευνας (πηγή: Salonica Campaign Society, φύλλο Γευγελή, 1-8-1916, κλίμακα 1:50.000, χαρτογραφία Καλλιόπη Ευκλείδου).

Πιο συγκεκριμένα, εάν επικεντρωθούμε στις διαφορετικές περιοχές που διερευνήθηκαν με τις γεωφυσικές τεχνικές, παρατηρούμε τα ακόλουθα: στην AREA 0 παρατηρούμε 2-3 μονοπολικές – διπολικές ισχυρές ανωμαλίες που οφείλονται στην παρουσία μεταλλικών θραυσμάτων (Εικόνα 8). Στην ίδια περιοχή υπάρχουν ασθενέστερες γραμμικές ανωμαλίες που σχετίζονται με τις καλλιεργητικές πρακτικές που λαμβάνουν χώρα στην ιδιοκτησία. Δεν υπάρχουν καθαρές ενδείξεις για την παρουσία αρχαιολογικών καταλοίπων. Το ίδιο συμβαίνει και με την AREA 1, η οποία χαρακτηρίζεται από ένα ασθενές ομαλό μαγνητικό υπόβαθρο, με κάποια γραμμικά και καμπύλα στοιχεία που σχετίζονται με νεότερες ανθρωπογενείς επεμβάσεις, καθώς και μερικές μεμονωμένες ισχυρές μαγνητικές ανωμαλίες που σχετίζονται με την παρουσία μεταλλικών αντικειμένων. Ισχυρές ανωμαλίες παρατηρούνται επίσης, στο βόρειο κεντρικό τμήμα της AREA 2. Οι ανωμαλίες αυτές είναι διπολικού χαρακτήρα και καταλαμβάνουν μεγάλη έκταση. Είτε σχετίζονται με παλαιότερα ανασκαφικά σκάμματα (στα οποία υπάρχουν διάφορα μεταλλικά αντικείμενα), ή έχουμε μεταλλικά κατάλοιπα/μπάζα από τις εκσκαφές που έγιναν στην περιοχή για την προμήθεια αδρανούς υλικού για την κατασκευή του παρακείμενου αυτοκινητόδρομου. Η Εικόνα 9 δίνει λεπτομέρειες από την διαγραμματική ερμηνεία των γεωφυσικών ενδείξεων στην περιοχή.

[2] Οι χωρικές ψηφιακές αναλύσεις πραγματοποιήθηκαν από τη δρ Καλλιόπη Ευκλείδου για τις ανάγκες της ανακοίνωσης Chatzitoulousis et. al. (in press), The transformations of a place and the recording of memory in space: the case of the cultural landscape of Idomeni, Kilkis, northern Greece. Ανακοίνωση στο διεθνές συνέδριο Unlocking Sacred Landscapes II: Digital Humanities and Ritual Space, Rethymnon, Crete, 19-21 October 2018.

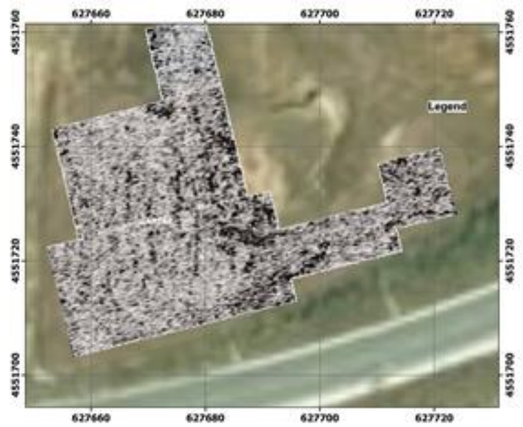


Εικόνα 8. Αποτελέσματα των γεωμαγνητικών μετρήσεων στις AREAS 0, 1 και 2.

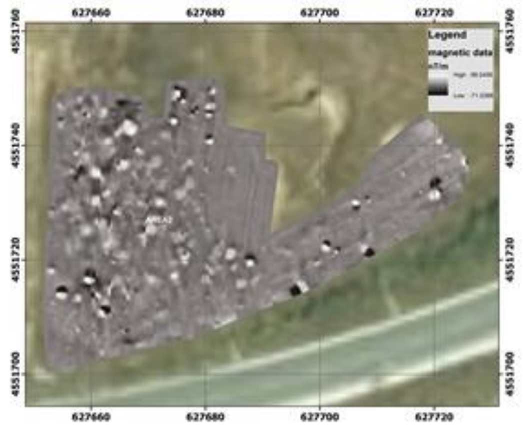


Εικόνα 9. Διαγραμματική ερμηνεία των γεωφυσικών ανωμαλιών στις AREAS 0, 1 και 2.

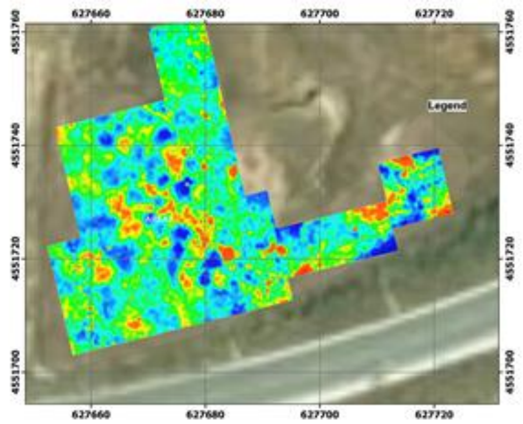
Το μεγαλύτερο ενδιαφέρον στην AREA 2 βρίσκεται στον χώρο των πρόσφατων αρχαιολογικών ανασκαφών, στα ΝΑ της περιοχής, όπου εμφανίζεται ένας αριθμός ασθενέστερων μονοπολικών/διπολικών ανωμαλιών που θα μπορούσαν να συσχετισθούν με νεολιθικές λακκοειδείς δομές ή ταφικά κατάλοιπα (Εικόνα 10). Οι οριζοντιογραφίες του γεωραντάρ δεν έδωσαν ενδείξεις έντονων ανακλαστήρων, το οποίο δικαιολογείται σε περίπτωση που δεν έχουμε κενά και λιθόκτιστα κατάλοιπα. Αντίθετα, εάν έχουμε λακκοειδή κατάλοιπα μπαζωμένα με φερτό αγώγιμο εδαφικό υλικό, δεν περιμένουμε την ύπαρξη έντονων ανακλαστήρων. Από την άλλη πλευρά, οι μαγνητικές ενδείξεις έδωσαν έναν αριθμό διπολικών ανωμαλιών μέσης – ασθενούς έντασης (Εικόνα 11). Όσες από αυτές είναι προσανατολισμένες με διεύθυνση Β-Ν (με τον αρνητικό πόλο προς τον Β) προέρχονται από την ύπαρξη μεταλλικών θραυσμάτων. Κάποιες άλλες όμως που είναι διαφορετικού προσανατολισμού και μεγαλύτερων διαστάσεων θα μπορούσαν να συσχετισθούν με την παρουσία αρχαιολογικών καταλοίπων. Οι πιο σαφείς ενδείξεις στον συγκεκριμένο χώρο προέρχονται από τις ηλεκτρικές διασκοπήσεις (Εικόνα 12). Κάποιες από τις περιοχές με έντονη ηλεκτρική αντίσταση συσχετίζονται με ενδείξεις που προέρχονται από τις υπόλοιπες τεχνικές και μπορούν να αποτελέσουν στόχους για μελλοντική διερεύνηση μέσω αρχαιολογικής ανασκαφής (Εικόνα 13). Από το σύνολο και των υπόλοιπων ενδείξεων φαίνεται ότι ο νεολιθικός οικισμός δεν εκτείνεται πέραν του εξάρματος στο οποίο έχουν εντοπιστεί ανασκαφικά λακκοειδείς δομές.



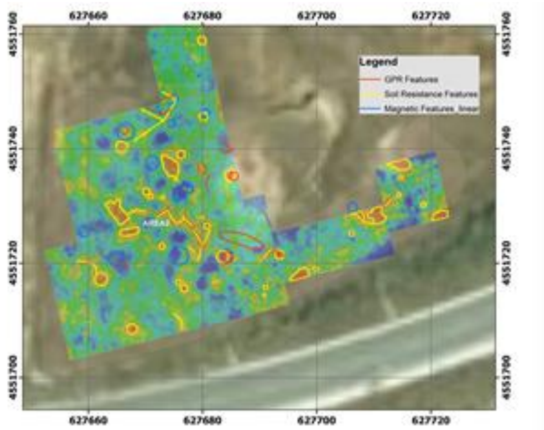
Εικόνα 10. Οριζοντιογραφία του GPR από την AREA 2 για βάθος 1.2-1.3μ. από την επιφάνεια του εδάφους.



Εικόνα 11. Αποτελέσματα των μαγνητικών διασκοπήσεων στην AREA2.

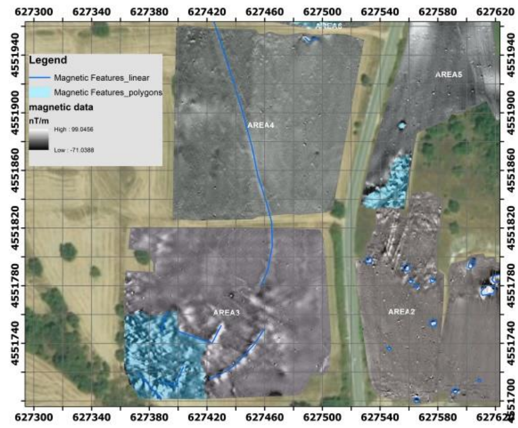


Εικόνα 12. Αποτελέσματα της ηλεκτρικής διασκόπησης στην AREA2.

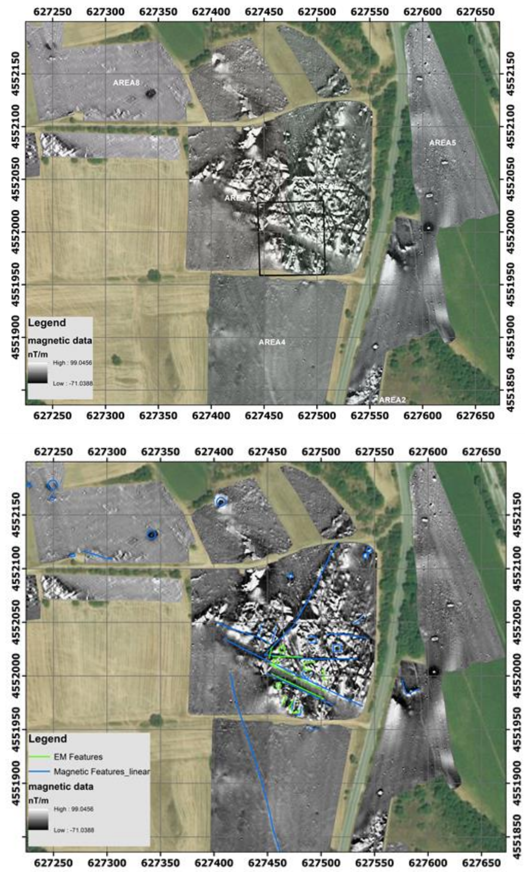


Εικόνα 13. Διαγραμματική ερμηνεία των γεωφυσικών ανωμαλιών στην περιοχή AREA 2 με υπέρθεση στον χάρτη των αποτελεσμάτων των ηλεκτρικών διασκοπήσεων

Στα δυτικά, οι περιοχές AREA 3 και AREA 4 παρουσιάζουν ένα ομαλό μαγνητικό υπόβαθρο, με εξαίρεση μία συγκέντρωση έντονων μαγνητικών ενδείξεων στα ΝΔ της περιοχής AREA 3 και μιας εκτεταμένης γραμμικής ανωμαλίας που διέρχεται κατά μήκος της περιοχής AREA 4 προς την κατεύθυνση του ΝΔ τμήματος της AREA 3 (Εικόνα 14). Εάν υποθέσουμε ότι η συσσώρευση αυτή στο ΝΔ τμήμα της AREA 3 απεικονίζει κατάλοιπα ενός εγκαταλελειμμένου νεότερου ιστορικού οικισμού, τότε ενδέχεται η γραμμική ανωμαλία που διατρέχει την AREA 4 να αποτελεί ένα μονοπάτι που να ενώνει τη νότια «γειτονιά»/μαχαλά στο AREA3 με τις υπόλοιπες «γειτονιές» που εκτείνονται βορειότερα στις περιοχές AREA 6 και AREA 7. Λίγα γραμμικά τμήματα διακρίνονται εντός της συσσώρευσης στην AREA 3 και ενδέχεται να απεικονίζουν τμήματα τοιχοδομών που παραμένουν ακόμα ανέπαφα.

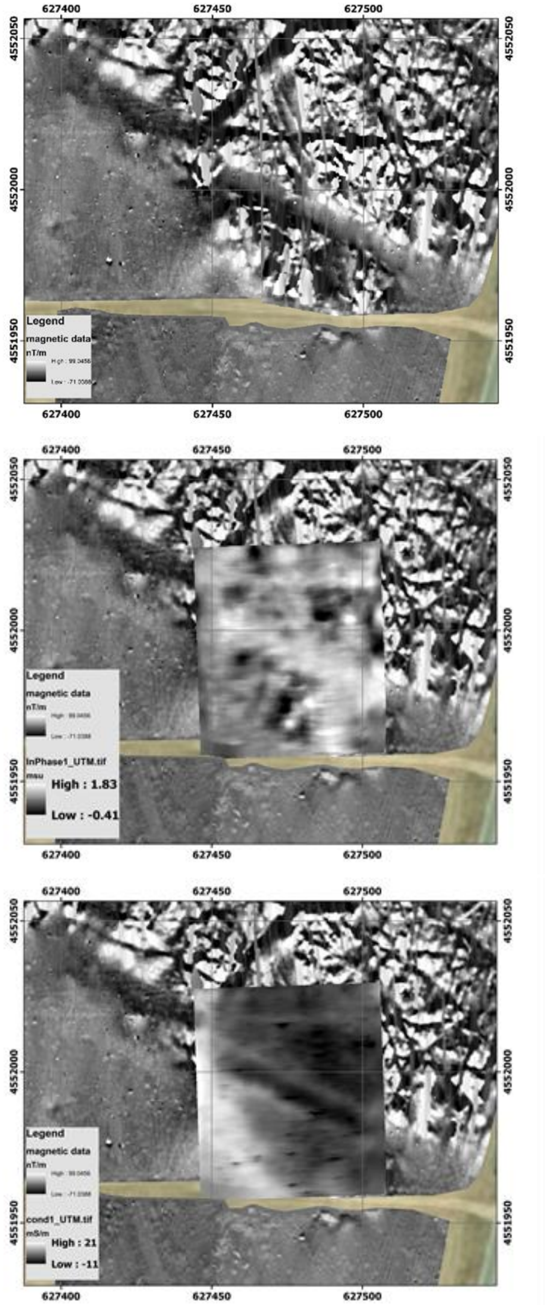


Εικόνα 14. Μαγνητικές ανωμαλίες στις AREA 3 και AREA 4.



Εικόνα 15. Αποτελέσματα μαγνητικών διασκοπήσεων στις περιοχές AREA 5, 6, 7 και 8 (Πάνω Εικόνα). Διαγραμματική ερμηνεία των γεωφυσικών ανωμαλιών στις περιοχές AREA 5, 6, 7 και 8 με υπέρθεση στον χάρτη των μαγνητικών μετρήσεων (Κάτω Εικόνα).

Βορειότερα, στις περιοχές AREA 5, 6, 7 και 8, μία έκταση μεγαλύτερη από 140x70μ., που εκτείνεται εντός των περιοχών AREA 6 και AREA 7 καταλαμβάνεται από μία συσσώρευση έντονων μαγνητικών ανωμαλιών (Εικόνα 15). Η οριοθέτηση της συγκέντρωσης αυτής είναι σχετικά γραμμική από διάφορες κατευθύνσεις, γεγονός το οποίο ενισχύει την υπόθεση ότι πρόκειται για κατάλοιπα οικισμού. Σε αυτό συνηγορούν τα γραμμικά στοιχεία που διακρίνονται εντός τού οικισμού. Στο νότιο τμήμα αυτού, μία ζώνη πλάτους 7μ. (δρόμος;) τον διατρέχει με διεύθυνση ΒΔ-ΝΑ, αφήνοντας μία μικρή νησίδα έντονων μαγνητικών ενδείξεων προς τα νότια. Η συγκεκριμένη ανωμαλία επιβεβαιώθηκε και από τις μετρήσεις της ηλεκτρικής αγωγιμότητας και της μαγνητικής επιδεκτικότητας από τις ηλεκτρομαγνητικές τεχνικές, οι οποίες επιπλέον μπόρεσαν να δώσουν και κάποιες πληροφορίες για λίγες ορθογώνιες δομές εντός του οικισμού (Εικόνα 16). Τα ανατολικά όρια του οικισμού φαίνεται να περιορίζονται στα δυτικά του δρόμου προς την Ειδομένη, αφού το τμήμα ανατολικά του δρόμου, AREA 5, φαίνεται να έχει ένα σχετικά ομαλό μαγνητικό υπόβαθρο. Εξαίρεση αποτελεί το νότιο τμήμα της AREA 5, προς την AREA 2, ενώ υπάρχουν ενδείξεις για την παρουσία κατοίκησης στον λόφο που εκτείνεται ΝΑ της AREA 5.

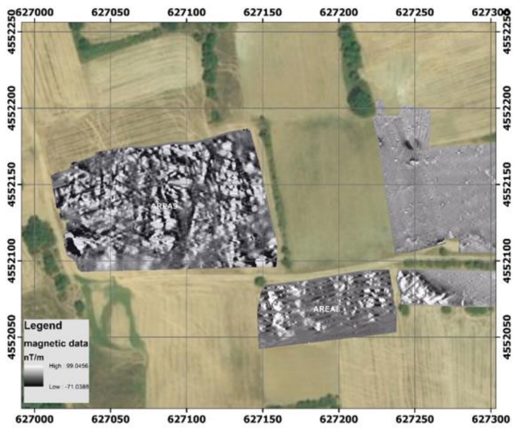


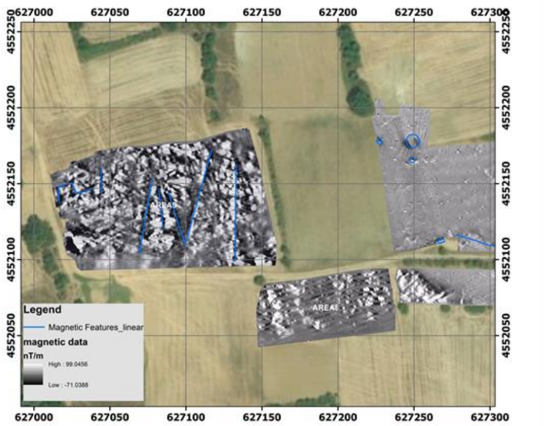
Εικόνα 16. Αποτελέσματα μαγνητικών διασκοπήσεων σε τμήμα της περιοχής AREA 6 (Πάνω Εικόνα). Απεικόνιση των αποτελεσμάτων της μαγνητικής επιδεκτικότητας (Μεσαία Εικόνα) και της ηλεκτρικής αγωγιμότητας (Κάτω Εικόνα) όπως προέκυψαν από τις ηλεκτρομαγνητικές διασκοπήσεις στο ίδιο τμήμα της περιοχής AREA 6.

Επίσης, ενδιαφέρον αποτελούν τρεις ισχυρές ανωμαλίες που βρίσκονται στο βόρειο τμήμα της AREA 5 (Εικόνα 17). Οι ανωμαλίες αυτές είναι έντονης μαγνήτισης, έχουν ορθογώνιο σχήμα διαστάσεων ~6x3μ. και είναι όλες προσανατολισμένες σε διεύθυνση Α-Δ. Αν και δεν μπορούμε να συνάγουμε συμπεράσματα ως προς τη φύση των συγκεκριμένων ενδείξεων, είναι σίγουρο ότι πρόκειται για ανθρωπογενείς κατασκευές.

Εικόνα 17. Αποτελέσματα μαγνητικών διασκοπήσεων στο βόρειο τμήμα της AREA 5. Διακρίνονται καθαρά οι τρεις έντονες ορθογώνιες μαγνητικές ανωμαλίες.

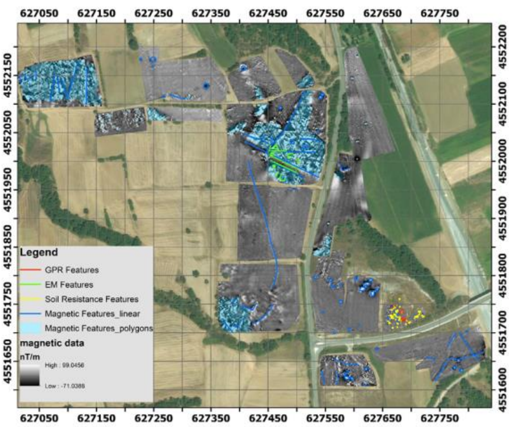
Τέλος, το δυτικότερο τμήμα της περιοχής που διερευνήθηκε (AREA 9) φαίνεται να καταλαμβάνεται και αυτό από μία πυκνή συγκέντρωση έντονων μαγνητικών ανωμαλιών που επεκτείνονται στο ΝΔ τμήμα της περιοχής AREA 8 (Εικόνα 18). Ορισμένα γραμμικά στοιχεία με διεύθυνση Β-Ν φαίνεται να διατρέχουν την περιοχή αυτή και ενδεχομένως αποτελούν ενδείξεις για την παρουσία δρόμων εντός του οικισμού.





Εικόνα 18. Αποτελέσματα μαγνητικών διασκοπήσεων στην περιοχή AREA 9 και ΝΔ τμήμα της AREA 8 (Πάνω Εικόνα). Διαγραμματική ερμηνεία των μαγνητικών ανωμαλιών στις αντίστοιχες περιοχές με υπέρθεση στον χάρτη των μαγνητικών μετρήσεων (Κάτω Εικόνα).

Το σύνολο των γεωφυσικών ενδείξεων παρουσιάζεται στην Εικόνα 19.



Εικόνα 19. Διαγραμματική ερμηνεία των αποτελεσμάτων των γεωφυσικών διασκοπήσεων στην Ειδομένη. Υπέρθεση στον χάρτη των αποτελεσμάτων των μαγνητικών διασκοπήσεων.

4. Συμπεράσματα

Ως γενικό συμπέρασμα, οι γεωφυσικές διασκοπήσεις ικανοποίησαν τους στόχους του ερευνητικού προγράμματος. Έμφαση δόθηκε στην περιοχή όπου έχουν βρεθεί και διερευνηθεί τα νεολιθικά ορύγματα και όπου ορισμένες γεωφυσικές ενδείξεις μπορεί να σχετίζονται με περισσότερα κατάλοιπα της προϊστορικής κατοίκησης.

Οι γεωφυσικές έρευνες επεκτάθηκαν σε διάφορα σημεία του χώρου γύρω από την ανασκαφική περιοχή και κυρίως σε εκτάσεις όπου εντοπίζονταν επιφανειακά ευρήματα (κυρίως κεραμική). Στην περιοχή υπήρχαν πολλά θραύσματα από οβίδες και κάλυκες, τα οποία δημιούργησαν αυξημένα επίπεδα θορύβου, ιδιαίτερα στις μαγνητικές μετρήσεις.

Οι ενδείξεις των γεωφυσικών διασκοπήσεων στις περιοχές πέραν του χώρου των ανασκαφών δεν φαίνεται να σχετίζονται με τη νεολιθική κατοίκηση. Το πιθανότερο είναι να σχετίζονται με κατάλοιπα οικιστικής εγκατάστασης, ενδεχομένως σύγχρονης με το νεκροταφείο των μεσοβυζαντινών χρόνων.

Σε κάθε περίπτωση, τα αποτελέσματα της γεωφυσικής έρευνας δίνουν πλήθος πληροφοριών για την διαχρονική κατοίκηση/χρήση του χώρου και τους μετασχηματισμούς της.

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ΑΝΑΖΗΤΩΝΤΑΣ ΤΟΝ ΤΑΦΟ ΤΟΥ ANDREAS VESALIUS ΣΤΗΝ ΖΑΚΥΝΘΟ
THE QUEST OF THE GRAVE OF ANDREAS VESALIUS IN ZAKYNTHOS

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Περίληψη

Έχοντας ως οδηγό τις πρόσφατες έρευνες ιστορικών χαρτών και πηγών σε σχέση με τον τόπο ταφής του Andreas Vesalius, του Βέλγου ανατόμου, πραγματοποιήθηκε γεωφυσική έρευνα κατά μήκος των δρόμων Χιώτη, Κολυβά, Χαριαγή, Λουκά Καρέρ, Κολοκοτρώνη, Μαρτζώκηδων και Δελάζαρη στο βόρειο τμήμα της πόλης της Ζακύνθου. Στόχος της έρευνας ήταν η μελέτη του υπεδάφους για τον εντοπισμό πιθανών χαρακτηριστικών που μπορούν να αποδοθούν σε τμήματα ιστορικών κτιρίων και ταφικών μνημείων. Η έρευνα έκανε χρήση του γεωραντάρ φθάνοντας ένα βάθος περίπου 3-4m από την σημερινή επιφάνεια των δρόμων.

Όπως αναμενόταν, οι μετρήσεις του γεωραντάρ επηρεάστηκαν σε μεγάλο βαθμό από τα δίκτυα κοινής ωφέλειας τα οποία εντοπίστηκαν στα επιφανειακά στρώματα του υπεδάφους. Η προσπάθεια των ερευνών εστιάστηκε στον εντοπισμό ανακλαστήρων μεγάλου πλάτους και βάθους μεγαλύτερο από 1m οι οποίοι θα μπορούσαν να αποδοθούν σε θεμελιώσεις κτιρίων τα οποία υπήρχαν πριν το νέο πολεοδομικό σχεδιασμό της νεότερης πόλης και τα οποία καταστράφηκαν από τον σεισμό του 1953.

Abstract

Having as a guide the recent study of historical maps and sources related to the burial place of the Belgian anatomist Andreas Vesalius, geophysical research was conducted along Chiotis, Koliva, Chariagi, Luka Karer, Kolokotroni, Marzokidon and Delasari streets, in the northern section of the modern town of Zakynthos (Greece). The aim of the research was to investigate the subsurface of the town in order to identify possible remains of historical buildings and funerary monuments. A ground penetrating radar (GPR) reaching a depth of about 3-4m from the current road surface was employed for the survey.

As expected, the GPR measurements were severely affected by the public utility networks located in the upper layers of the subsoil. The whole effort of the campaign was thus focused on identifying wide reflectors of depths greater than 1m, which could be attributed to foundations of buildings that existed before the great earthquake of 1953 and the subsequent rebuilding of the town.

Λέξεις Κλειδιά/Keywords: Andreas Vesalius, Zakynthos, GPR survey.

1. Εισαγωγή

Πρόσφατες έρευνες ιστορικών χαρτών και πηγών διερεύνησαν τον τόπο ταφής του Andreas Vesalius, του Βέλγου ανατόμου, ο οποίος μέχρι σήμερα πιθανολογείτο ότι άφησε την τελευταία του πνοή πάνω στο πλοίο που ναυάγησε κοντά στην ακτή του νησιού της Ζακύνθου στις 15 Οκτωβρίου 1564 (Biesbrouck & Steeno 2010; Biesbrouck & Steeno 2012; Biesbrouck, Goddeeris & Steeno 2012; Biesbrouck 2014; Dirix 2014). Η τελευταία μελέτη των ιστορικών πηγών θέτει επίσης υπό αμφισβήτηση την υποτιθέμενη ταφή του Vesalius στην παραλία του Λαγανά προτείνοντας ως επικρατέστερη την άποψη ότι η ταφή του έγινε στην αυλή της εκκλησίας Santa Maria delle Grazie, η οποία είχε ιδρυθεί το 1488 για να περάσει στην ιδιοκτησία ενός νεοσύστατου μοναστηριού που ίδρυσε μία Φραγκισκανή αδελφότητα στις αρχές του 16ου αιώνα (Κατραμής 1880: 455; Ζώης 1963: 509). Στον χώρο κοντά της εκκλησίας ενταφιάζονταν Καθολικοί και ξένοι (Zuallardo 1595: 85-86). Τα νεότερα χρόνια το μοναστήρι είχε εγκαταλειφθεί και μόνο η εκκλησία διατηρούνταν. Η σεισμική δόνηση της 12ης Αυγούστου 1953 έπληξε την περιφέρεια Ιονίων νήσων και είχε ως αποτέλεσμα την κατάρρευση των περισσότερων από τα κτίρια της πόλης της Ζακύνθου και μαζί με αυτά της εκκλησίας της Santa Maria delle Grazie. Για την ανοικοδόμηση της πόλης, έγινε απομάκρυνση των ερειπίων (σύμφωνα με προφορικές μαρτυρίες προς την πλευρά της θάλασσας, γεγονός που μάλλον επιβεβαιώνεται από την σύγκριση της ακτογραμμής από τους νεότερους και ιστορικούς χάρτες) και ακολούθησε ένας νέος σχεδιασμός της πόλης, τελείως διαφορετικός από τον προηγούμενο.

Σε μία προσπάθεια επανακαθορισμού της θέσης της εκκλησίας Santa Maria delle Grazie, προηγήθηκε μία μελέτη των ιστορικών χαρτών κάνοντας χρήση Γεωγραφικών Συστημάτων Πληροφοριών (GIS) (Déderix & Plessas 2014; Déderix et al 2014). Στην προσπάθεια αυτή χρησιμοποιήθηκαν:

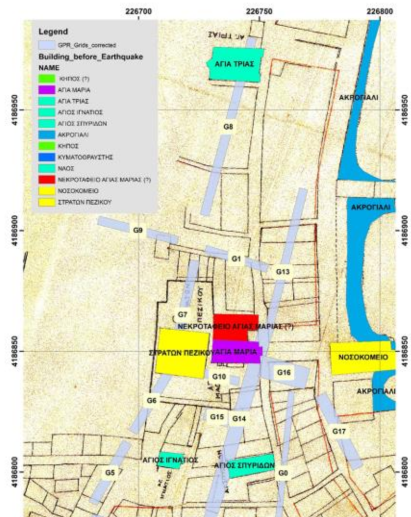
1) Ο Χάρτης του 1892 που δημοσιεύτηκε το 1970 από τον Δ. Ζήβα και 2) Ο χάρτης που ήταν αποθηκευμένος στα προσωπικά αρχεία του Γιάννη Παπαδάτου, δικηγόρου Ζακύνθου και Προέδρου του Μουσείου Δ. Σολωμού και Επιφανών Ζακυνθίων. Ο συγκεκριμένος χάρτης προηγείται του σεισμού του 1953, παρόλο ότι ενημερώθηκε το 1954, πριν από την ανοικοδόμηση της Ζακύνθου (Εικόνα 1).

Εικόνα 1. Υπέρθεση του γεωαναφερμένου χάρτη του 1953/1954 στην δορυφορική εικόνα από Google Earth.

Με βάση τις αναλύσεις που έγιναν και με έμφαση στην γεωαναφορά των ιστορικών χαρτών, έγινε εφικτός ο προσδιορισμός της θέσης της εκκλησίας Santa Maria delle Grazie που προσδιορίζεται πλησίον της διασταύρωσης των οδών Κολυβά και Κολοκοτρώνη, απέναντι από το ξενοδοχείο Palatino. Ο δρόμος που διέτρεχε την πόλη μπροστά από την εκκλησία στα τέλη του 19ου και αρχές του 20ου αιώνα, ακολούθησε διαφορετικό προσανατολισμό από την σημερινή οδό Κολυβά, με συνέπεια τα κατάλοιπα της εκκλησίας, όπως φαίνεται και από την γεωαναφορά του χάρτη, να βρίσκονται κυρίως κάτω από ιδιωτικές κατοικίες και εν μέρει κάτω από το δρόμο (οδό Κολυβά).

2. Οι Γεωφυσικές Έρευνες

Με βάση τα αποτελέσματα των χωρικών αναλύσεων των ιστορικών χαρτών, η έρευνα οδηγήθηκε στο επόμενο στάδιο με την διερεύνηση του υπεδάφους σε όποια σημεία αυτό ήταν εφικτό, δηλαδή κατά μήκος των δρόμων που βρίσκονται περιμετρικά της εκκλησίας. Η γεωφυσική έρευνα πραγματοποιήθηκε σε συνεργασία με την Βελγική Σχολή Αθηνών την περίοδο 20-23 Σεπτεμβρίου 2017. Οι μετρήσεις έγιναν κατά μήκος των δρόμων Χιώτη, Κολυβά Χαριαγή, Λουκά Καρέρ, Κολοκοτρώνη, Μαρτζώκηδων και Δελάζαρη. Η Εικόνα 2 παρουσιάζει την θέση των γεωφυσικών καννάβων κατά μήκος των δρόμων μαζί με την θέση των κτηρίων που φαίνονται από τον γεωαναφερμένο χάρτη του 1953/54.



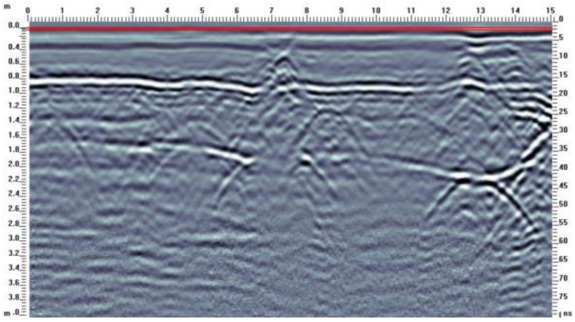
Εικόνα 2. Υπέρθεση των γεωφυσικών καννάβων πάνω στον γεωαναφερμένο χάρτη του 1953/1954. Στον ίδιο χάρτη τονίζονται τα κτήρια τα οποία έχουν αναγνωριστεί από τον χάρτη του 1953/54 καθώς και η ακτογραμμή που υφίστατο πριν τον σεισμό του 1953. Στην ίδια εικόνα φαίνεται και η κωδικοποίηση των γεωφυσικών καννάβων.

Στόχος της γεωφυσικής έρευνας ήταν η μελέτη του υπεδάφους για τον εντοπισμό πιθανών θέσεων που μπορούν να αποδοθούν σε τμήματα ιστορικών κτηρίων και ταφικών μνημείων. Στα πλαίσια της έρευνας αυτής έγινε χρήση της γεωφυσικής μεθόδου του Γεωραντάρ (GPR). Οι μετρήσεις λήφθηκαν με το όργανο NOGGIN GPR Smart Cart Plus με κεραία των 250MHz (Εικόνα 3). Η δειγματοληψία των μετρήσεων έγινε ανά 2.5cm κατά μήκος παράλληλων οδεύσεων που απείχαν 25cm μεταξύ τους. Η κατακόρυφη δειγματοληψία ήταν της τάξης των 0.5ns και το βάθος διείσδυσης έφθασε τα 3-4m από την σημερινή επιφάνεια του εδάφους.

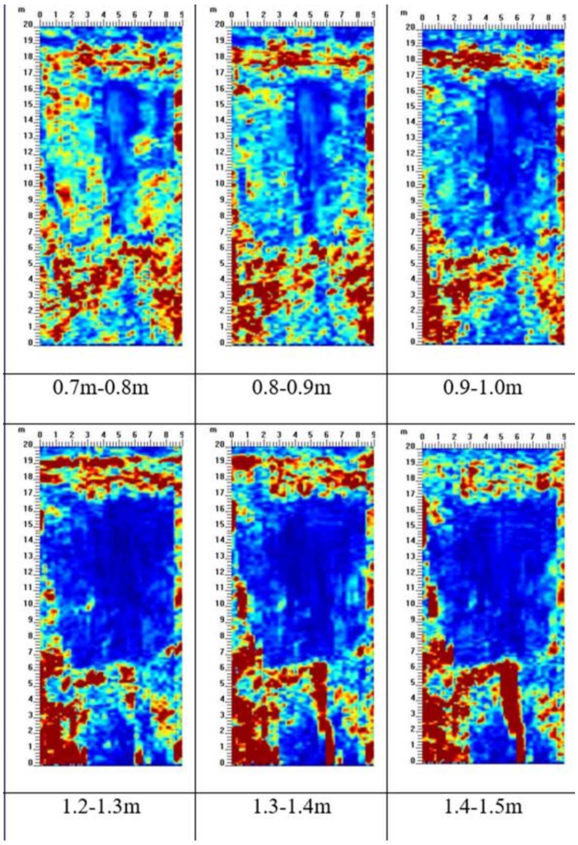
Εικόνα 3. Η μονάδα NOGGIN GPR Smart Cart Plus με κεραία των 250MHz που χρησιμοποιήθηκαν στις έρευνες στην Ζάκυνθο.

Η απόφαση να δοθεί προτεραιότητα στην χρήση του γεωραντάρ σε σχέση με την εναλλακτική μέθοδο της ηλεκτρικής τομογραφίας (ERT), η οποία μπορεί και αυτή να χρησιμοποιηθεί μέσα σε αστικό περιβάλλον, πάρθηκε με βάση την πιο γρήγορη λήψη των μετρήσεων και την καλύτερη ανάλυση και δειγματοληψία αυτών.

Οι μετρήσεις βασίστηκαν στην μέθοδο της ανάκλασης (common offset methodology) με την οποία ο πομπός και ο δέκτης διατηρούνται σε σταθερή απόσταση μεταξύ τους και κινούνται κατά μήκος μιας γραμμής μελέτης στην επιφάνεια του εδάφους συλλέγοντας μετρήσεις από τα ανακλώμενα ηλεκτρομαγνητικά κύματα μιας συγκεκριμένης συχνότητας με σταθερό βήμα δειγματοληψίας. Το τελικό αποτέλεσμα (ραδιόγραμμα) δίνει πληροφορίες της στρωματογραφίας του εδάφους κατά μήκος της όδευσης (Εικόνα 4). Η ύπαρξη υλικών με διαφορετικές ηλεκτρικές ιδιότητες από το περιβάλλον εδαφικό πλαίσιο στο οποίο ανήκουν, δημιουργούν ανακλάσεις οι οποίες φέρουν μία μορφή υπερβολής. Ο συνδυασμός ραδιογραμμάτων από παράλληλες οδεύσεις δημιουργεί μία τρισδιάστατη απεικόνιση του υπεδάφους από την οποία μπορούμε να εξάγουμε οριζόντιες τομές με αυξανόμενο βάθος (οριζοντιογραφίες), οι οποίες απεικονίζουν την κατανομή των ανακλαστήρων σε διαφορετικά βάθη (Εικόνα 5).



Εικόνα 4. Παράδειγμα ραδιογράμματος από τις μετρήσεις του γεωραντάρ στην Ζάκυνθο.



Εικόνα 5. Παράδειγμα οριζοντιογραφιών σε διαφορετικά βάθη από τον κάνναβο G16 απέναντι από το ξενοδοχείο Palatino.

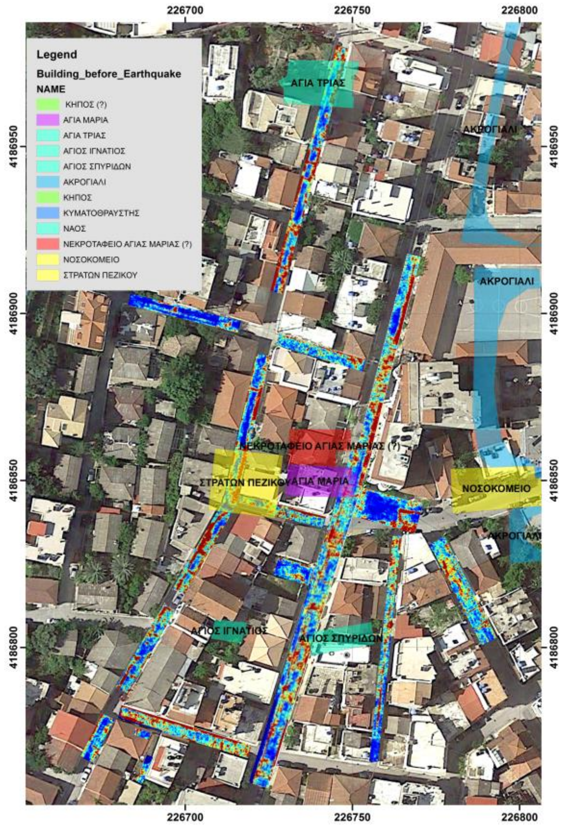
Είναι προφανές ότι για την καλύτερη απόδοση των συγκεκριμένων ανακλαστήρων θα πρέπει να υπάρξει μία συνδυαστική εφαρμογή αλγορίθμων επεξεργασίας οι οποίοι συνεισφέρουν στην σωστή τοποθέτηση των ραδιογραμμάτων, την αποκοπή των σημάτων του υποβάθρου και του εξωτερικού θορύβου και την ενίσχυση των ασθενών σημάτων που καταγράφονται σε μεγαλύτερα βάθη, Η μελέτη ισχυρών ανακλαστήρων βοηθάει επίσης στον υπολογισμό της ταχύτητας μετάδοσης της ηλεκτρομαγνητικής ακτινοβολίας στο συγκεκριμένο εδαφικό υπόβαθρο και οδηγεί σε έναν πιο ακριβή υπολογισμό του βάθους των τελικών οριζοντιογραφιών.

3. Αποτελέσματα των Μετρήσεων του Γεωραντάρ

Για την ερμηνεία χρησιμοποιήθηκε το λογισμικό ArcGIS όπου οι οριζόντιες τομές που παρουσιάζουν το μεγαλύτερο ενδιαφέρον γεωαναφέρθηκαν στα προηγούμενα χαρτογραφικά υπόβαθρα. Για την ανάλυση και ερμηνεία των ενδείξεων του γεωραντάρ χρησιμοποιήθηκαν τόσο τα ραδιογράμματα όσο και οι οριζόντιες τομές για την περιγραφή των ανωμαλιών. Οι ανακλάσεις που παρατηρούνται στις οριζόντιες τομές ομαδοποιήθηκαν σε δύο κατηγορίες με βάση το βάθος στο οποίο παρατηρούνται: επιφανειακοί ανακλαστήρες με βάθος μέχρι το 1,0m και ανακλαστήρες σε βάθη μεγαλύτερα του 1,0m. Θα πρέπει να επισημανθεί ότι σε επιφανειακά βάθη, οι περισσότερες ισχυρές ανωμαλίες σχετίζονται με δίκτυα κοινής ωφέλειας (αποχετεύσεις, ύδρευση, οπτικές ίνες κ.λ.π.). Με τον τρόπο αυτό, η ταξινόμηση των ανακλαστήρων βοήθησε στον διαχωρισμό μεταξύ χαρακτηριστικών που οφείλονται σε νεότερα δίκτυα κοινής ωφέλειας και σε στοιχεία τα οποία ενδεχομένως έχουν κάποιο αρχαιολογικό ενδιαφέρον και που θα μπορούσαν να δικαιολογηθούν από την παρουσία παλαιότερης θεμελίωσης κτιρίων. Η επιλογή των ανακλάσεων έγινε με βάση τις τιμές των πλατών, του βάθους στο οποίο παρουσιάζονται και των διαστάσεών τους. Τα στοιχεία αυτά συσχετίσθηκαν και με τον γεωαναφερμένο χάρτη του 1953/54.

Στην Εικόνα 6 παρουσιάζεται το μωσαϊκό όλων των καννάβων, με τους βαθύτερους ανακλαστήρες (οριζοντιογραφίες 1-1,5m) ενώ ταυτόχρονα φαίνονται και τα πιο σημαντικά κτίρια που είναι αποτυπωμένα στον ιστορικό χάρτη του 1953/54.

Πιο αναλυτικά, στο βόρειο τμήμα της περιοχής (κάνναβοι G8-G89, G1 και G13) παρατηρούνται κυρίως τα δίκτυα κοινής ωφέλειας, κάτι το οποίο συμβαίνει και με τους περισσότερους καννάβους που διερευνήθηκαν. Οι σωλήνες των δικτύων φαίνονται καθαρά στα ραδιογράμματα του γεωραντάρ (Εικόνα 7) και αποτυπώνονται επίσης και στις οριζοντιογραφίες με αυξανόμενο βάθος. Υπάρχουν κυρίως δύο είδη δικτύων, ένα το οποίο βρίσκεται σε ένα βάθος περίπου 2m από την επιφάνεια των δρόμων και ένα άλλο που βρίσκεται πιο επιφανειακά, περίπου 0.5-1m από την επιφάνεια των δρόμων. Θα πρέπει να σημειώσουμε ότι οι συγκεκριμένοι σωλήνες έδωσαν πολλαπλές ανακλάσεις στα ραδιογράμματα που παρήχθησαν και πολλές φορές επισκίασαν τις βαθύτερες ανακλάσεις. Επίσης, η υπογραφή των ανακλάσεων που οφείλεται στις σωληνώσεις δεν είναι ομοιογενής, αλλά πολλές φορές παρουσιάζει διακοπές στην πορεία των σωληνώσεων. Τα δίκτυα διατρέχουν τον μεγάλο άξονα της διεύθυνσης των δρόμων και σε πολλές περιπτώσεις φαίνονται οι διακλαδώσεις τους που απολήγουν στα φρεάτια που έχουν τους μετρητές και τα οποία καλύπτονται από μεταλλικό καπάκι. Η καταγραφή αυτών με μονάδες GPS ήταν χρήσιμη για να δούμε ποιες από τις κάθετες γραμμικές ανωμαλίες που προέρχονται από τα κεντρικά δίκτυα απολήγουν σε αυτές. Από τους ανακλαστήρες που καταγράφηκαν σε κάθε περιοχή, τα επιφανειακά σήματα οφείλονται κυρίως στις νεότερες επεμβάσεις. Υπάρχουν όμως κάποιοι μεγάλου πλάτους ισχυροί ανακλαστήρες οι οποίοι παρουσιάζονται σε διάφορα τμήματα των καννάβων G1, G9 και G13 σε μεγαλύτερα βάθη τα οποία μπορούν να συσχετισθούν με την παρουσία θεμελίων παλαιότερων κτιρίων (Εικόνα 7: κόκκινα τετράγωνα). Η ερμηνεία των ανακλαστήρων παρουσιάζεται στην Εικόνα 8 όπου φαίνονται δύο κύριες περιοχές βαθιών έντονων ανακλαστήρων.



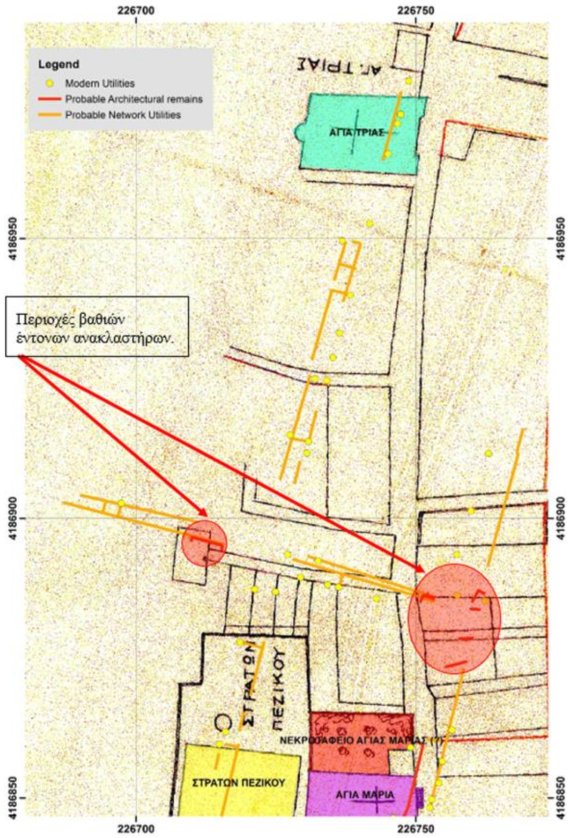
Εικόνα 6. Μωσαϊκό οριζόντιων τομών του γεωραντάρ για βάθη 1-1,5m. Στον συγκεκριμένο χάρτη έχουν σημειωθεί τα πιο σημαντικά κτίρια που είναι αποτυπωμένα στον ιστορικό χάρτη του 1953/54.

Στο νότιο τμήμα της περιοχής, σε οικόπεδο επί των οδών Χιώτη και Δελάζαρη, ανασκαφές που διεξήχθησαν από την Εφορεία Αρχαιοτήτων Ζακύνθου (υπό την εποπτεία της Διευθύντριας Χ. Μερκούρη) έφεραν στο φως τοιχοδομές Ελληνιστικής περιόδου, ένα τάφο Βυζαντινής περιόδου και δύο Ενετικά πηγάδια. Δοκιμαστικές μετρήσεις έγιναν σε διάφορα επίπεδα εντός της ανασκαφής, στο βόρειο τμήμα της οποίας φαίνεται να υπάρχει εγκάρσιος τοίχος σε βάθος περίπου 70-120cm από το τότε υφιστάμενο ανεσκαμμένο επίπεδο. Στο νότιο τμήμα της ίδιας ιδιοκτησίας, οι μετρήσεις του γεωραντάρ που έγιναν στο μη ανεσκαμμένο επίπεδο υποδεικνύουν την ύπαρξη ενός έντονου ανακλαστήρα σε βάθος περίπου 2.5m από την επιφάνεια του πατώματος του κτιρίου. Γενικά, η συσχέτιση των μετρήσεων του γεωραντάρ με τα αποτελέσματα των ανασκαφών έδωσε σημαντικές πληροφορίες για το βάθος των αναμενόμενων στόχων.

Εικόνα 7. Μωσαϊκό οριζόντιων τομών του γεωραντάρ από το βόρειο τμήμα της περιοχής ενδιαφέροντος.

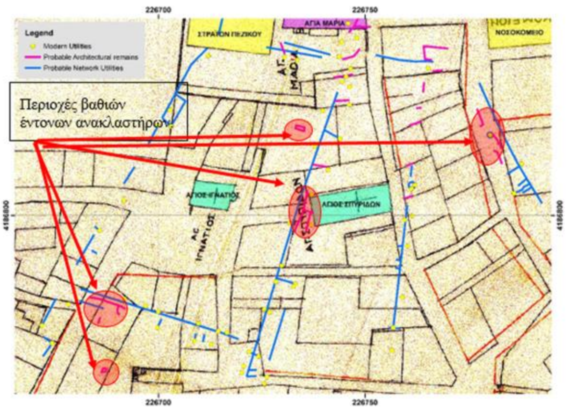
Παρόμοιο ενδιαφέρον παρουσιάζουν και οι δρόμοι περιμετρικά της ανασκαφής (νότιο τμήμα της οδού Χιώτη και δυτικό τμήμα της οδού Δελάζαρη). Μεγάλου πλάτους ανακλαστήρες εντοπίστηκαν σε βάθη πάνω από 2.4m, και ιδιαίτερα στην αρχή του καννάβου G4 (επί της οδού Χιώτη) και κατά μήκος όλης της έκτασης της οδού Δελάζαρη (κάνναβος G11). Γενικά η περιοχή παρουσιάζει ενδιαφέρον και οι σημαντικού πλάτους βαθιές ανακλάσεις βρίσκονται σε συμφωνία με τα βάθη των αρχιτεκτονικών δομών που εντοπίστηκαν στην ανασκαφή.

Υπάρχουν ακόμα περισσότερα σημεία στην ίδια περιοχή, όπως για παράδειγμα,, στον κάνναβο G15, που ενδέχεται να σχετίζονται με βαθιά αρχιτεκτονικά ερείπια. Επίσης κάποιοι έντονοι ανακλαστήρες εμφανίζονται στην θέση που φαίνεται να ήταν κτισμένος ο Άγιος Σπυρίδωνας. Η ερμηνεία των ανακλαστήρων παρουσιάζεται στις Εικόνες 9 και 10.



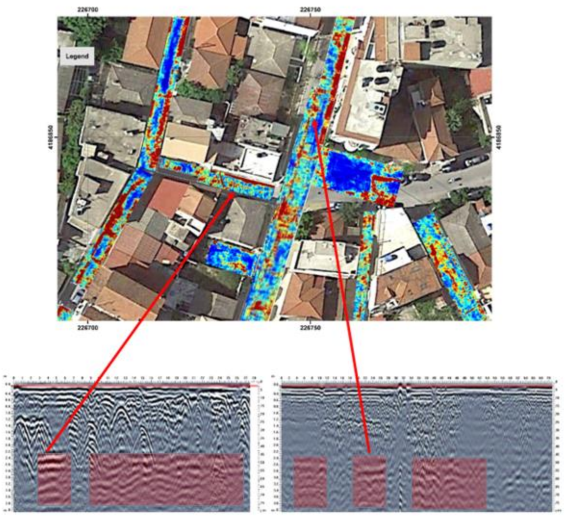
Εικόνα 8. Ερμηνεία γεωφυσικών αποτελεσμάτων από το βόρειο τμήμα της περιοχής ενδιαφέροντος και υπέρθεση στον χάρτη του 1953/54.

Εικόνα 9. Ερμηνεία γεωφυσικών αποτελεσμάτων. Μωσαϊκό οριζόντιων τομών του γεωραντάρ από το Νότιο τμήμα της περιοχής ενδιαφέροντος.



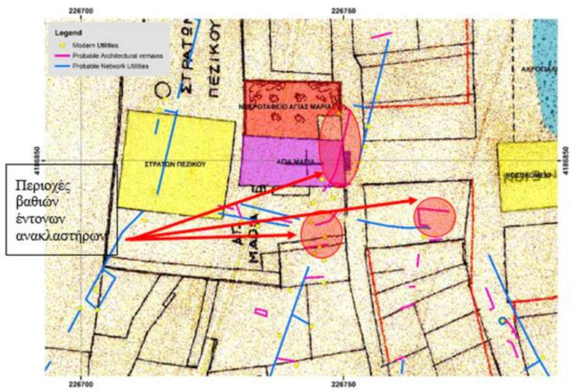
Εικόνα 10. Ερμηνεία γεωφυσικών αποτελεσμάτων από το Νότιο τμήμα της περιοχής ενδιαφέροντος και υπέρθεση της διαγραμματικής ερμηνείας αυτών στον χάρτη του 1953/54.

Οι ενδείξεις του γεωραντάρ στο κεντρικό τμήμα της περιοχής δεν διαφοροποιούνται και πολύ από τις υπόλοιπες. Και πάλι, οι μετρήσεις έχουν επηρεαστεί από τα υπεδάφεια δίκτυα κοινής ωφέλειας. Εστιάζοντας την προσοχή μας όμως στα μεμονωμένα ραδιογράμματα και στις βαθιές μεγάλου πλάτους ανωμαλίες (οι οποίες διατηρούν ένα παρόμοιο βάθος με τις προηγούμενες), μπορούμε να εντοπίσουμε κάποιες περιοχές που χρίζουν μεγαλύτερης προσοχής (Εικόνα 11). Πιο συγκεκριμένα, στον κάνναβο G10 (δυτικό τμήμα της οδού Κολοκοτρώνη) και στο τμήμα του καννάβου G13 (οδός Κολυβά) που βρίσκεται απέναντι από το ξενοδοχείο Palatino, έχουμε ένα μεγάλο αριθμό από βαθιές ανακλάσεις μεγάλου πλάτους που μπορούν να συσχετισθούν με παλαιότερες αρχιτεκτονικές θεμελιώσεις. Θα πρέπει να σημειωθεί ότι η συγκεκριμένη περιοχή εμπίπτει ανατολικά της θέσης στην οποία έχει προσδιοριστεί η θεμελίωση της εκκλησίας Santa Maria delle Grazie.



Εικόνα 11. Μωσαϊκό οριζόντιων τομών του γεωραντάρ από το κεντρικό τμήμα της περιοχής ενδιαφέροντος. Στα αντίστοιχα ραδιογράμματα φαίνονται οι ενδεικτικές μεγάλου πλάτους βαθύτερες ανωμαλίες που μπορούν να συσχετισθούν με παλαιότερες θεμελιώσεις κτηρίων.

Παρόμοιο ενδιαφέρον παρουσιάζει και ο κάνναβος G16, νότια του ξενοδοχείου Palatino, στο ανατολικό τμήμα του οποίου φαίνεται μία έντονη ορθογώνια ανωμαλία (δείτε την Εικόνα 5), η οποία επεκτείνεται σε ένα εύρος βάθους 1.3-1.8m. Η ερμηνεία των ανακλαστήρων παρουσιάζεται στην Εικόνα 12.

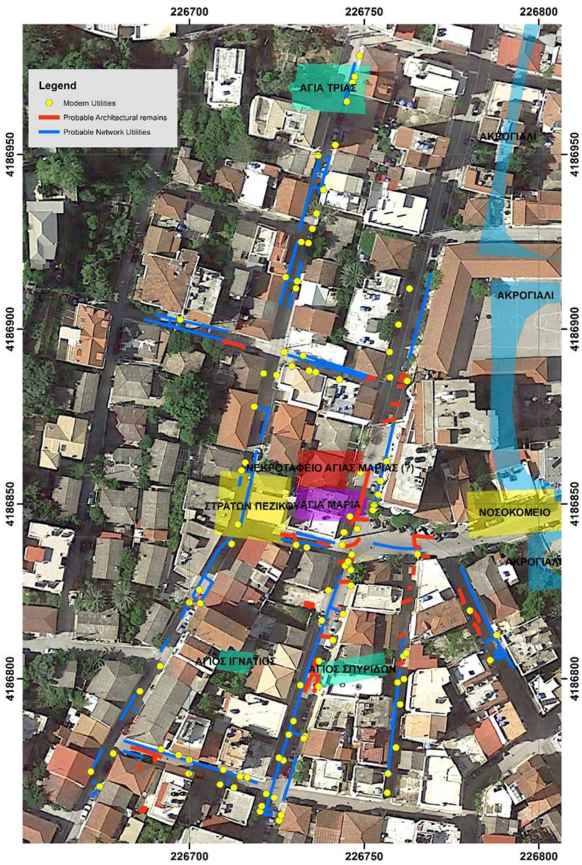


Εικόνα 12. Ερμηνεία των γεωφυσικών αποτελεσμάτων από το κεντρικό τμήμα της περιοχής ενδιαφέροντος και υπέρθεση αυτών στον χάρτη του 1953/54.

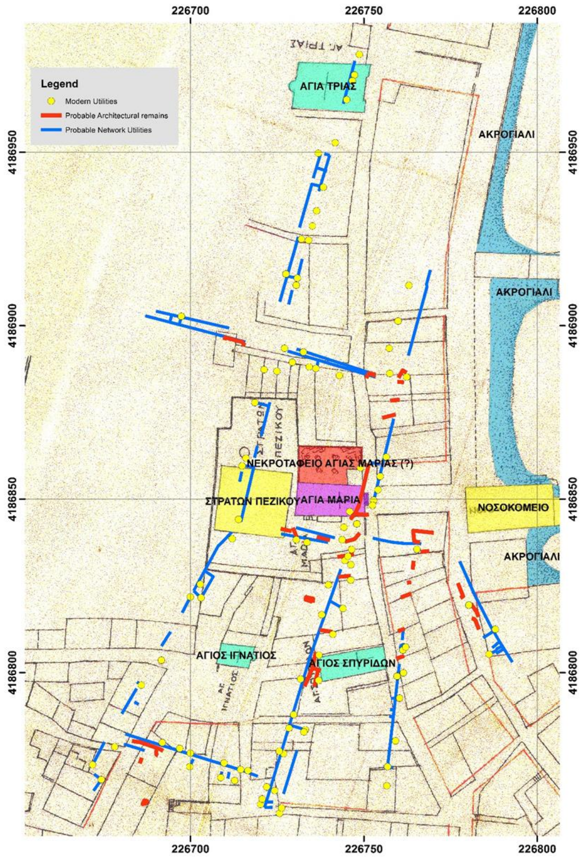
4. Τελικά Συμπεράσματα

Η μέθοδος του γεωραντάρ αποδείχθηκε ως η πλέον ικανοποιητική για να δώσει ένα μεγάλο αριθμό υπεδάφειων ενδείξεων μέσα σε ένα αρκετά θορυβώδες και διαταραγμένο εδαφικό πλαίσιο στο αστικό περιβάλλον της πόλης της Ζακύνθου. Αρκετοί ανακλαστήρες εντοπίστηκαν σε διαφορετικά τμήματα των οδών που διερευνήθηκαν γύρω από την περιοχή στην οποία φαίνεται να υπήρχε η εκκλησία Santa Maria delle Grazie και το νεκροταφείο αυτής. Μία συγκέντρωση ανακλαστήρων επάνω στο βόρειο τμήμα της οδού Κολυβά συμπίπτει με το δυτικό τμήμα της εκκλησίας του Αγίου Σπυρίδωνα. Βορειότερα, στην συμβολή των οδών Κολοκοτρώνη και Κολυβά, εντοπίστηκαν παρόμοια χαρακτηριστικά, χωρίς όμως να μπορούμε να συνάγουμε με βεβαιότητα ότι οι ανακλαστήρες αυτοί συμπίπτουν με την ανατολική πλευρά της εκκλησίας Santa Maria delle Grazie, αν και όπως προσδιορίζεται από την γεωαναφορά των ιστορικών χαρτών πριν τον σεισμό του 1953, θα πρέπει να εμπίπτει στην μέση της οδού Κολυβά, απέναντι από το ξενοδοχείο Palatino. Σε κάθε περίπτωση, οι παραπάνω ενδείξεις μαζί με ένα μικρό αριθμό άλλων που παρουσιάζονται στις Εικόνες 13 και 14, διαφοροποιούνται από τις νεότερες επεμβάσεις και είναι πολύ πιθανόν να οφείλονται σε προγενέστερες κατασκευές (μη καλά διατηρημένες θεμελιώσεις ή ακόμα και συγκεντρώσεις από οικοδομικά υλικά).

Μπορεί οι γεωφυσικές έρευνες και γενικότερα η μέθοδος της γεωπληροφορικής να μην έδωσαν την προσδοκώμενη επιβεβαίωση για τον τάφο του Andreas Vesalius, αλλά προσέφεραν πολύτιμες πληροφορίες για την αποτύπωση του χώρου πριν στον σεισμό του 1953 που ισοπέδωσε τα περισσότερα κτήρια της πόλης και δεν άφησε σαφείς ενδείξεις για την θέση της εκκλησίας Santa Maria delle Grazie. Όμως η προσέγγιση που έγινε με τις συγκεκριμένες τεχνικές σε συνδυασμό με την αρχειακή έρευνα που προηγήθηκε, ιδιαίτερα από τον Theo Dirix, έδωσε χρήσιμες πληροφορίες για το χωρικό πλαίσιο στο οποίο ανήκε αυτή τροφοδοτώντας ακόμα περισσότερο το ενδιαφέρον για την ιστορική διαδρομή και την ανεύρεση του τάφου του διάσημου αυτού Βέλγου ανατόμου.



Εικόνα 13. Ερμηνεία γεωφυσικών αποτελεσμάτων και υπέρθεση των κύριων ανακλαστήρων στην δορυφορική εικόνα του Google Earth.



Εικόνα 14. Ερμηνεία γεωφυσικών αποτελεσμάτων και υπέρθεση των κύριων ανακλαστήρων στον χάρτη του 1953/54.

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MONITORING BURIAL MOUNDS IN THE YAMBOL PROVINCE: DEPLOYING MOBILE TECHNOLOGY TO IMPROVE CULTURAL HERITAGE PROTECTION

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Περίληψη

Τα τελευταία δέκα χρόνια, το προσωπικό του Περιφερειακού Ιστορικού Μουσείου με συναδέλφους από το Περιφερειακό Αρχαιολογικό πρόγραμμα Tundzha (TRAP) επισκέφθηκαν πάνω από 700 τύμβους στην περιοχή Γιαμπόλ. Χρησιμοποιώντας κινητές ψηφιακές εφαρμογές ΓΣΠ, όπως ArcPad και FAIMS, συλλέχτηκαν σημεία GPS, μετρήσεις και φωτογραφίες και έγιναν περιγραφές της κατάστασης κάθε τύμβου. Κατά τη διάρκεια της τελευταίας επίσκεψης, το FAIMS χρησιμοποιήθηκε για να παράγει ένα ψηφιακό σύνολο χωρικών δεδομένων που ενσωματώνει δομημένα δεδομένα με πολυμέσα. Τα τελικά σύνολα δεδομένων αποθηκεύονται στο εθνικό μητρώο αρχαιολογικού χώρου, γνωστό ως Αρχαιολογικός Χάρτης της Βουλγαρίας (AMB). Ο χάρτης AMB είναι προσβάσιμος στο διαδίκτυο για εθνικές και τοπικές υπηρεσίες.

Οι τύμβοι είναι λοφίσκοι με ύψος που κυμαίνεται από 0,5 έως 5 μέτρα σε ύψος και πάνω από 50 μέτρα διάμετρο. Δημιουργήθηκαν κατά την Πρώιμη Εποχή του Χαλκού έως την αρχή της περιόδου της Ύστερης Αρχαιότητας και συνδέονται με τις ταφικές πρακτικές. Το εμφανές τους μέγεθος και το πλούσιο τους περιεχόμενο, τους έχουν καταστήσει στόχο από κυνηγούς θησαυρών. Τα τελευταία χρόνια έχουν ξεκινήσει δίκες που αφορούν κυνηγούς θησαυρών οι οποίοι κατηγορούνταν για την καταστροφή μνημείων πολιτιστικής κληρονομιάς. Οι ακριβείς συντεταγμένες των επηρεαζόμενων αρχαιολογικών χώρων αποτελούν πλέον στοιχεία σε τέτοιες δίκες.

Η ικανότητα συστηματικής συλλογής δομημένων δεδομένων και πολυμέσων σε απομακρυσμένες περιοχές, η ακριβής καταγραφή της θέσης και η ενσωμάτωση πληροφοριών από πολλαπλές ομάδες που λειτουργούν ταυτόχρονα είναι ζωτικής σημασίας για την αποτελεσματική διαχείριση της πολιτιστικής κληρονομιάς και την επιτυχή προστασία των αρχαιολογικών χώρων.

Abstract

During the last 10 years, Regional Historical Museum staff with colleagues participating in the Tundzha Regional Archaeological Project (TRAP) visited over 700 burial mounds in the Yambol province. Using mobile, GIS applications such as ArcPAD and FAIMS, they collected GPS points, photos, and described the condition of each mound. In the last season, FAIMS was used to produce digitally-born, spatially-enhanced dataset that integrated structured data with multimedia. Resulting datasets are stored in the national archaeological site register, known as the Archaeological Map of Bulgaria (AMB). AMB is accessible online by national and local institutions.

Burial mounds are earthen features ranging from 0.5 to 5 m in height and up to 50 m diameter. They were built from the Early Bronze Age to the beginning of Late Antique period in connection with mortuary practices. Their conspicuous size and wealthy contents have made them a target for treasure-hunting. During the recent years more trials have resulted in treasure hunters charged for destroying monuments of culture. Precise coordinates of affected archaeological sites now form evidence during court trials.

The ability to systematically collect structured data and multimedia in remote areas, to record location precisely, and integrate information from multiple simultaneously running teams is crucial for effective cultural heritage management and successful protection of archaeological sites.

Keywords: field survey, cultural heritage, Yambol, FAIMS

1. Introduction

Yambol province is situated in southeast Bulgaria on the border with Turkey. The province is divided into five municipalities and encloses an area of 3,335.5 sq km, which include some 2,300 archaeological sites (Fig. 1). Two museums with a total of 30 staff members are managing the combined cultural heritage of the province.

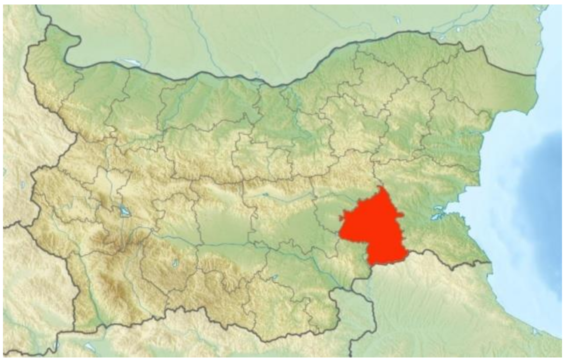

Figure 1. Yambol province

The terrain in Yambol region is level to hilly. Yambol-Elhovo's field is separated from the Upper Thracian valley by the Manastirskite and Svetiilijskite heights. From the east and south-east the field is bordered by the Bakadzhitsite heights, the northwest hills of the Sakar Mountain and the Derventskite heights (Стефанов 2002, 39). Favorable natural and climatic conditions in the Lower and Middle courses of the Tundzha River must have attracted human settlement since the distant past.

In 2008, the Tundzha Regional Archaeological Project (TRAP) began operating in the Yambol province under the direction of Ass. Prof. Shawn Ross, Dr. Adela Sobotkova, Iliya Iliev and Stefan Bakardzhiev. Its aims were to diachronically investigate the cultural landscapes of the Middle Tundzha River using non-destructive field methods such as the pedestrian survey, satellite remote sensing, and digital recording employing relational databases, mobile computing, and geographic information systems (GIS). The first results from the project were published in a book *The Tundzha Regional Archaeological Project Elhovo Survey* (Iliev et al. 2012) and a final report is forthcoming (Ross et al. 2018).

While conducting total-coverage surface survey, TRAP teams also started monitoring the condition of burial mounds throughout Yambol. Burial mounds are conspicuous earthen features ranging from 0.5 to 5 m in height and up to 50 m diameter (Fig. 2, Fig. 3 and Fig. 4). They were built from the Early Bronze Age to the beginning of Late Antique period in connection with mortuary practices. Burial mounds are cultural monuments of national significance. Old topographic maps of the Yambol province show locations of over thousand mounds. TRAP teams, therefore, used digitized maps to guide mound visits.

Figure 2. Burial mound in grassland

Figure 3. Ploughed up burial mound

Figure 4. Scrubby burial mound in an agricultural field

2. Mixed paper and digital recording in 2010

In the initial season of mound monitoring in 2010, TRAP teams used a combination of paper and digital forms (ArcPAD, the mobile client of ArcGIS) for field data collection. The paper and digital workflow facilitated fast progress in the field as well as easy navigation, and spatial data capture. It, however, required many hours of post-processing to produce analysis-ready data. Paper forms had to be digitized, images downloaded, matched to forms and labelled, and daily records streamlined, requiring two to three hours of meticulous work before the daily record could be summarized and utilized to plan the next day. Omissions and errors were time-consuming to fix, delaying field progress. Data management was onerous and far from bulletproof. The project ran a local server (MS Server 2008) as a central storage and backup for shared data. Each member, however, had to transfer their dataset to the server manually, which turned out to be an issue for compliance. Major data loss ensued when a couple of unsecured computers were stolen at the end of the 2010 season, revealing that team members had failed to follow manual backup procedures.

3. FAIMS Mobile and digital workflow in 2017

Field recording in 2017 was conducted digitally on mobile devices running the 'TRAP Burial mounds' customisation of FAIMS Mobile. FAIMS Mobile is open-source, customisable software designed specifically to support field research in archaeology and other disciplines. It allows for offline collection of structured, text, multimedia and geospatial data on multiple Android devices, which are synchronised and backed up when they connect to a server (Ballsun-Stanton et al. 2018).

The aims of a completely digital workflow were to (1) avoid post-processing of paper forms and multimedia, (2) ensure completeness and consistency of data upon its creation in the field, and (3) automate synchronisation of data between multiple devices, and (4) have an analysis-ready dataset at the press of a button every night. FAIMS Mobile satisfied all the requirements for offline, spatially-aware operation, for data validation, multimedia integration and automatic labelling, with the ability to view legacy GIS datasets and tweak digital forms in the field.

TRAP Burial mounds module allowed users to view topographic maps and existing vector layers. Users could navigate with the help of a GPS and a location cursor, and collect information on burial mounds including GPS points, photos and sketches, and structured and free-entered data.

In the field each team carried an Nvidia Shield k1 tablet with the TRAP Burial mounds module, a powerbank, handheld GPS (Garmin eTrex), and a Panasonic G1 camera (or similar DSLR camera which facilitated image capture in raw format). Teams used the digital topographic maps, vector layers, and a GPS pointer to navigate to the mounds. Once at a site, a team member captured mound photos and coordinates with the tablet using onboard GPS sensor and camera, and proceeded to fill out the structured form for each mound.

Each record included dimensions, shape, surrounding land use, and condition/preservation status of each mound (see https://github.com/FAIMS/Burial for screenshots and module wireframe). Most entry fields were structured and input was constrained to predetermined values, editable on server. For example, the preservation was assessed on one-to-five Likert scale, where one meant a mound was in pristine condition and five denoted an extinct mound. Each constrained field also allowed users to place comments in the 'Annotation' tab or mark certainty of observation in 'Certainty' tab, thus facilitating digital 'scribbling on the margins' at attribute-level. All of the captured photos and coordinates were integrated within the mound record, and were searchable and editable on the tablet.

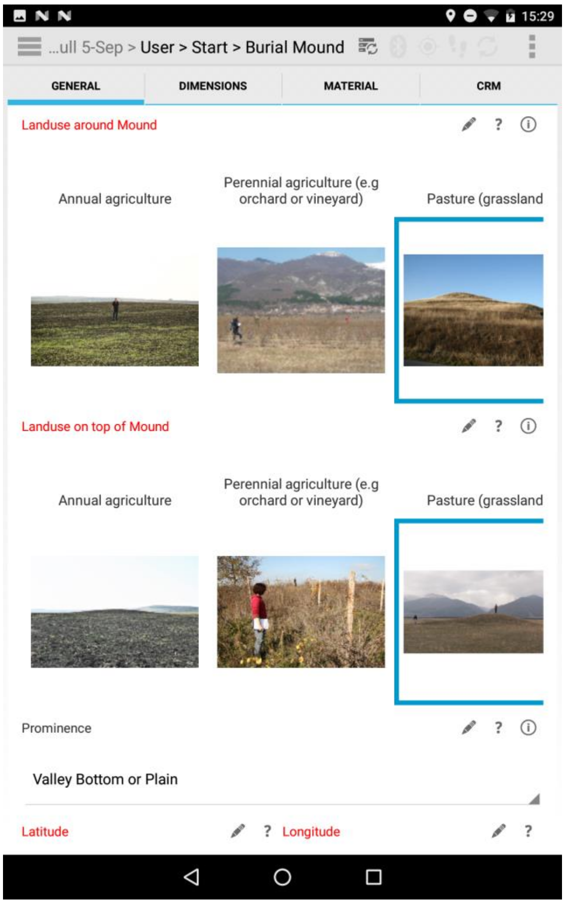

Figure 5. Screenshot of FAIMS Burial mound module with picture dictionaries used for land use classification.

To assist with field decision-making, additional contextual help was provided at attribute level, containing verbal and pictorial guidelines (Fig. 5). The essential items were marked with red asterisks. To verify complete entry, users could also press the Validation button in the sidebar and get an updated list of missing items. Validation button was an all-time favorite for all teams as the instant list of 'to do' prevented omissions and obviated visual inspection of tablet in the glaring Mediterranean sun. As a result of validation, critical information such as mound dimensions, coordinates, overview photo, and cultural resource evaluation were captured without failure.

At the end of the day, the teams brought their tablets to the base, plugged them in and switched on the wifi connectivity. The tablets would connect to the FAIMS server over local network, and automatically exchange new data with the server and every other team's tablet. FAIMS server is a Ruby on Rails application running on Ubuntu on a palm-sized computer (New Unit of Computing). The FAIMS server functions as an appliance, e.g. like a router, which requires merely being switched on at the beginning of the project and can then be left running. It creates its own local network and searches for new data on that network on the basis of timestamps and usernames. For administrative purposes, the server is accessible via a web interface from any device on local network. Users with login and access privileges can interact with the data, and create, or otherwise administer existing modules.

To get all data in analysis-ready format during 2017, team leaders used the default exporter functionality of the FAIMS server. The default exporter is a built-in plugin that pushes all synchronized information out in an archive that includes spreadsheets, shapefiles, and sqlite database, with all multimedia automatically labeled by record identifier and sorted by category (*e.g.*, Mounds - Overview pictures, Mounds - Detail pictures, Mounds - Associated Material). Automatic labelling of all multimedia saved us at least an hour of manual photo labelling daily. It also made the labelling of the backup photos from digital SLR cameras much faster.

The immediate availability of data after arrival from field allowed the team leaders to consult and resolve any issues or ambiguities they encountered in the field, and proceed to next-day planning. The only remaining post-processing involved the backup data, including GPS coordinates and high resolution DSLR photos, which students downloaded and processed via DNR Garmin and Adobe Creative Cloud Bridge application respectively, taking ca 30 mins per team.

4. Archaeological Map of Bulgaria - Final Data Repository

After the fieldwork finished, the data on all documented mounds were entered in the Bulgarian national register of archaeological sites, the Archaeological Map of Bulgaria (AMB). The AMB serves as a central archive for all archaeological data in Bulgaria. AMB records resolve to the level of a site. Each site record includes basic archaeological information: site type, size, chronology, cultural characteristics, associated materials and information about written sources. It also includes geographic information, such as modern administrative borders, soils, orography, and hydrography. Finally, there is information about the protection status of the monument and recommendations for future investigation.

Collecting field data in structured forms with digital systems that can capture and integrate information from internal or external GPS sensors improves the spatial precision and overall quality of AMB records. With precise coordinates and standardized measures of condition and preservation, the heritage practitioners can more effectively allocate resources where they are needed most.

5. Burial mounds as a cultural heritage

Burial mounds have been protected by law since the Bulgarian independence. The first "Law for the Antiquities" dates to 10th February 1911. On 22nd October 1962, Disposition 1711 declared all burial mounds to be cultural monuments of national significance. The current "Cultural Heritage Law" was accepted on 13th March 2009 (ДВ 19, 2009) with last reforms on 8th July 2016 (ДВ 52, 2016). According to this Law, "cultural heritage" by definition encompasses all archaeological sites, including burial mounds (point 2a (1), point 6 (1), and point 146 (1) from the Law). They are the carriers of "historical memory, national identity and have scientific or cultural value" (point 2 (1) of the Law). They are "the testament to human presence and activity" (point 7 (1) and point 146 (1) of the Law). According to the Law, cultural heritage should be protected through a "systematic process of searching, study, identification, documentation, registration, conservation, restoration, and adaptation" (point 8 (1) from the "Law for Culture Heritage"). The purpose of cultural heritage protection is to preserve the heritage for next generations and for the prosperity of the community.

In the 21st century, digital medium plays a large role in the protection of cultural heritage. Working with mobile GIS systems is the only way to generate spatially accurate data for the AMB. The ability to deploy in the field a standardized, digital workflow for the documentation and classification of mound condition helps collect data in systematic manner and thus establish a baseline for future visits. It also makes the deployment of a heritage app possible, opening an avenue to engaging local community in mound protection. Registered with the use of mobile, GIS-aware systems, the location of archaeological sites is precise and can be situated on cadastral plans and topographic maps (Fig. 6). Accurate location of cultural heritage helps with their management and mitigation during development.

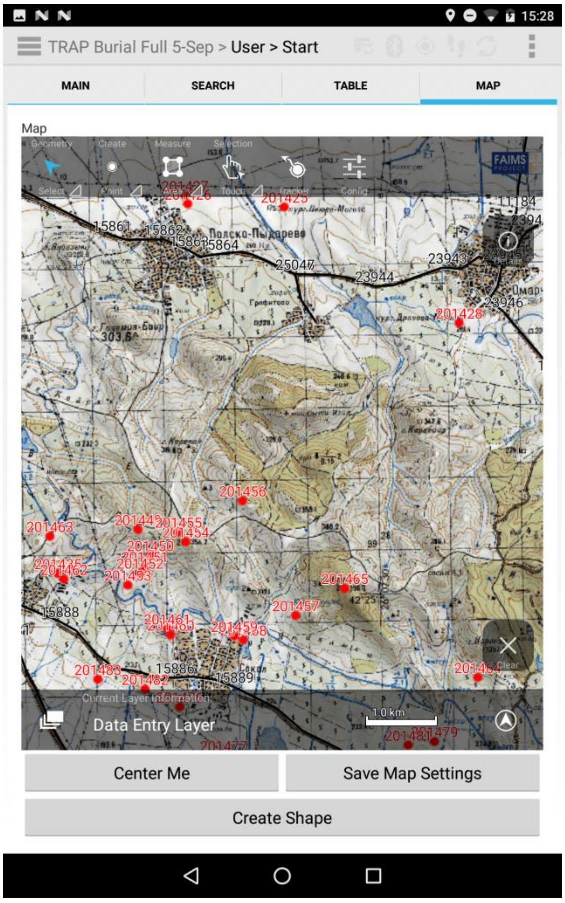

Figure 6. Screenshot of the FAIMS module with a topographic basemap and points indicating burial mounds

In addition to location, digital mound monitoring captures mound condition in systematic and standardized way. Information about what cultural heritage suffers allows the museum staff to allocate resources to the most needed sites. The hemispherical form of burial mounds makes them easy to recognize in the landscape. Their conspicuous size and wealthy contents have made them a target for treasure-hunting (Loulanski and Loulanski 2017). In the last decade treasure hunters have been convicted of destroying burial mounds thanks to accurate evidence provided through technologically-enabled fieldwork. Precise coordinates of affected archaeological sites now form evidence during court trials. High-quality field documentation helps effectively protect cultural heritage and is an essential prerequisite to infrastructure projects and development.

6. Conclusion

Over 700 burial mounds have been revisited and digitally documented by TRAP teams in Yambol, and their present condition recorded in the Archaeological Map of Bulgaria. This number represents about a half of all burial mounds in the Yambol province, which makes it one of the most detailed registers for this type of archaeological site in the territory of Bulgaria. The ability to systematically collect structured data and multimedia in remote areas, to record location precisely, and integrate information from multiple simultaneously running teams is crucial for effective cultural heritage management and successful protection of archaeological sites.

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Session 2

Geospatial Technologies for Mapping and Monitoring Cultural Heritage

A GIS APPLICATION FOR ARCHAEOLOGICAL INFORMATION BASED ON ORTHOPHOTOS OF THE MAZOTOS SHIPWRECK IN CYPRUS

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Περίληψη

Η παρούσα εργασία περιγράφει την ανάπτυξη μιας εφαρμογής GIS με βάση ορθοφωτογραφίες υψηλής ανάλυσης του Ναυαγίου του Μαζωτού, το οποίο βρίσκεται στα -44 μ βάθος στη θαλάσσια περιοχή νότια της Κύπρου. Στόχος της εφαρμογής είναι να εξαχθούν πληροφορίες σχετικά με το φορτίο του ναυαγίου, μέσω της χρησιμοποίησης του χαρτογραφικού υποβάθρου, δηλαδή τις ορθοφωτογραφίες που λήφθηκαν υποβρυχίως καθώς και τη βάση δεδομένων του έργου, και τα δύο προερχόμενα από τη ανασκαφική διαδικασία του ναυαγίου. Η ανωτέρω εφαρμογή υλοποιείται μέσω ενός τοπικού συστήματος συντεταγμένων και ερευνά το πώς οι γεωχωρικές απεικονιστικές μέθοδοι θα μπορούσαν να χρησιμεύσουν στην εξαγωγή αρχαιολογικών πληροφοριών μέσα από τη χρήση του λογισμικού ArcGIS. Το προϊόν αυτό θα δώσει τη δυνατότητα στον τελικό χρήστη να εντοπίσει σε ένα περιβάλλον GIS τη θέση και τις πληροφορίες των αμφορέων που έχουν βρεθεί και τεκμηριωθεί επί τόπου, είτε έχουν αφαιρεθεί και ανελκυστεί. Τα αποτελέσματα αξιολογούνται εκτός από την απαραίτητη τεχνολογική άποψη, και από εκείνη ενός αρχαιολόγου, παρουσιάζοντας την ευκολία πρόσβασης, την πληρότητα και την αποτελεσματικότητά της.

Abstract

This paper describes the development of a GIS application based on high resolution orthophotos of the Mazotos Shipwreck which lies at -44 m depth in the sea area south of Cyprus. The aim of the application is to extract information of the shipwreck's cargo by utilizing the cartographic background, thus the orthophotos taken underwater and the produced database of the Project, both created during the shipwreck's excavation process. The above application implements local coordinate system and investigates how geospatial imaging methods could serve in extracting archaeological information by using the ArcGIS software. This product will enable the end-user to detect into a GIS environment the position and information of amphorae that have been found and documented in situ, or, either removed and lifted. The results are evaluated apart from the essential technological point of view and from that of an archaeologist, presenting the ease of access, its completeness and efficiency.

Λέξεις Κλειδιά/Keywords: Databases, ArcGIS, Cultural Heritage, Digital Orthophotos, Cyprus, Shipwreck, Chian Amphora, 4th century BC, Seaborne Trade, Underwater Archaeological Survey

1. Introduction

The Geographic Information Systems (GIS) application, of this study, is based on high-resolution orthophotos of a shipwreck and by implementing a local coordinate system it seeks to investigate how geospatial imaging methods could serve in extracting archaeological information using a GIS software.

The main aims of the study are: a) to extract information of the shipwreck's cargo by utilizing the cartographic background, b) to explore how the geospatial methods could serve to extract archaeological information, c) to deepen into the methods of imaging the geospatial and archaeological information using processes and technologies of the Geographic Information Systems (GIS) and d) to develop an application through the use of the ArcGIS software and its environment.

The goal of the development of this product is to enable the end-users to detect into a GIS environment the position and information of shipwreck's cargo either as this was found in situ or unearthed and revealed later during the course of the excavations. Likewise, any other actions related to these objects, for example when removed or lifted to the surface, would also be traceable. The results are evaluated from the technological point of view, as well as from the archaeological one, presenting among others the ease of access and its completeness and efficiency.

2. Site of the Study

The Mazotos Shipwreck is located 1.5 nautical miles off the shores of the homonymous village and lies at a -44 m depth in the southern sea of Cyprus. It was discovered in 2006, and since 2007 an underwater project has been carried out by the Maritime Archaeological Research Laboratory (MARELab) of the Archaeological Research Unit of the University of Cyprus, under the supervision of the director, Dr Stella Demesticha in collaboration with the Department of Antiquities, and it has been excavated from 2010 onwards.

The Mazotos Shipwreck is unique not only due to the important discovery, its great archaeological significance or the large volume of finds, but also to the pioneering excavation procedures that are followed, which combine innovative interdisciplinary research methods. More information on the shipwreck can be found in scientific publications (see Demesticha 2011; Demesticha et al. 2014; Demesticha 2017; Scarlatos et al. 2010; Skarlatos & Rova 2010; Skarlatos et al. 2012).

3. The Archeological Process and the challenges underwater

Archaeologists often characterize the excavation method as a destruction since it is a state of loss of the successive layers of soil formed in time and which are disrupted once and for all.

Therefore, it is understood that an excavation is equivalent to a destruction, for that land has been kept for years, affectionately. The ultimate goal to the archaeological process is to preserve the archaeological information. Everything in the excavation aim at the least possible destruction of things and, the best possible recording of the conditions in which they were found (Sakellarakis, 2006).

Archaeological information is often not inferred directly but at a later stage. The finding or findings that carry with them the information should go through a particular procedure as this is illustrated in Figure 1.

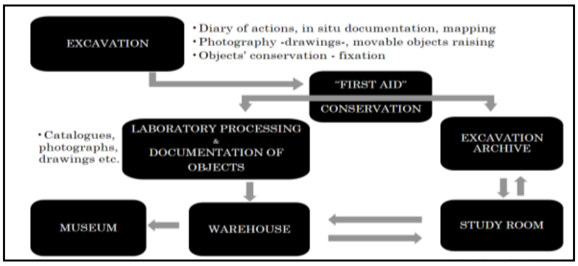

Figure 1. The Archaeological Process Scheme (after Mazarakis - Ainian 2015).

Furthermore, these challenges including the ones during excavation and laboratory, consist by the on-site detailed documentation of movable and immovable objects and recording of their context and conditions of exposure, as well as the related actions taken while revealing those finds.

Most of the times, as well as at Mazotos Shipwreck case study in particular, there are cultural objects that vary in size, shape, morphological complexity and the time for the necessary measurements is often minimal – also due to the depth of -44m where diving limitations occur. The archaeological practice should also reflect adaptability to the recording practice due to variety, complexity and diversity of finds. (Pavlidis et al. 2007).

Figure 2. Detail of the cargo from the Mazotos shipwreck indicating the amount, density and complexity of objects (Papademetriou & Toli 2017, cover image)

Another challenge is the best possible in situ preservation or the protection from deterioration caused from new environment and time and long-lasting conservation. Finally, measures of accuracy and fidelity must take place as regards the description, presentation, and illustration of objects (ibid).

3a Constrains for archaeology underwater

Undoubtedly, when working in the underwater environment several problems arise (see Muckelroy 1978, pp. 24-48). Likewise, while on board, prevailing weather and wind conditions at the sea, especially where a maritime accident happened, create a remote and challenging working environment for the scientists.

The challenges and needs for the underwater archaeological practice include the same amount of effort and organization of what has been described above, about the ones on land. From the logistics point of view, other concern the cost of an underwater project where expensive equipment is needed and that comes against the lack of funding. Along with the latter the different conservation techniques needed due to the new environment after surfacing have their own and extra expenditure.

Such conditions require a demanding daily recording and monitoring of all the actions related to the finds such as tagging, excavating, cleaning, moving and preparing an amphora to be lifted to the surface, in situ preservation and treatment needs, photography, and conservation stage when desalinating at the museum etc.

Divers themselves are the biggest problem underwater according to Muckelroy (1978), and their ability to perform effectively in terms of both speed and quality of work (ibid. p. 36) is affected. Communication and task accomplishment is also an issue.

The underwater environment and the nature of a wrecksite create several problems even for the execution of traditional processes like documentation and mapping of the excavation:

A) Excavation procedures encounter large concentration of finds and as mentioned before that leads to numerous actions and their interrelated to information. and thus, to a large volume of Databases.

To overcome the above challenges the Maritime Archaeological Research Laboratory (MARELab) of the University of Cyprus kept all excavation seasons' collected data thoroughly stored on the Excavation Databases.

B) Mapping procedures due to the depth of -44 m must deal with limited light, short stay time at the bottom. There exist problems of mapping accuracy and the precise modelling of main findings.

Besides, as regards underwater mapping the data acquisition should not be undertaken by inexperienced users personnel (divers) (Skarlatos & Rova 2010).

ID	MuseumNu	NoPiece	Material	Kind	Type	Description	Trench	Layer	Date	Dive_No	Work_Type	
P0001	NM0118	1	Pottery	Amphora	Chian	Missing part of	F2-T1-T4-T6	0	21/11/2007	1	Labelled	πλαστικός δισ
P0001	NM0118	1	Pottery	Amphora	Chian	Missing part of	F2-T1-T4-T6	0	23/11/2007	3	Labelled	Μπρούτζινη τ
P0001	NM0118	1	Pottery	Amphora	Chian	Missing part of	F2-T1-T4-T6	0	25/05/2008	2	Labelled	Κίτρινο ταμπ
P0001	NM0118	1	Pottery	Amphora	Chian	Missing part of	F2-T1-T4-T6	0	08/05/2010	3	Labelled	Placed photog
P0001	NM0118	1	Pottery	Amphora	Chian	Missing part of	F2-T1-T4-T6	0	20/05/2011	6	Monitored	Label loose, c
P0001	NM0118	1	Pottery	Amphora	Chian	Missing part of	F2-T1-T4-T6	0	22/05/2011	3	Labelled	Attached stop
P0001	NM0118	1	Pottery	Amphora	Chian	Missing part of	F2-T1-T4-T6	0	23/05/2011	3	Monitored	Bronze tag, Bl
P0001	NM0118	1	Pottery	Amphora	Chian	Missing part of	F2-T1-T4-T6	0	27/05/2011	3	Labelled	Hard plastic ta
P0001	NM0118	1	Pottery	Amphora	Chian	Missing part of	F2-T1-T4-T6	0	08/06/2011	6	Photographed	Amphora
P0001	NM0118	1	Pottery	Amphora	Chian	Missing part of	F2-T1-T4-T6	0	08/06/2011	1	Cleaned	Amphora
P0001	NM0118	1	Pottery	Amphora	Chian	Missing part of	F2-T1-T4-T6	0	08/06/2011	7	Lifted	Broken amph
P0001	NM0118	1	Pottery	Amphora	Chian	Missing part of	F2-T1-T4-T6	0	09/06/2011	0	Cleaned	Chian amphor
P0001	NM0118	1	Pottery	Amphora	Chian	Missing part of	F2-T1-T4-T6	0	11/06/2011	99	Moved	Amphora mov
P0001	NM0118	1	Pottery	Amphora	Chian	Missing part of	F2-T1-T4-T6	0	13/06/2011	99	Labelled	Given museum
P0002	NM0110	1	Pottery	Amphora	Chian	Intact chian am	F2-T1-T4-T6	0	25/05/2008	2	Labelled	Κίτρινο ταμπ
P0002	NM0110	1	Pottery	Amphora	Chian	Intact chian am	F2-T1-T4-T6	0	31/05/2011	8	Excavated	Amphora (exc
P0002	NM0110	1	Pottery	Amphora	Chian	Intact chian am	F2-T1-T4-T6	0	31/05/2011	9	Moved	Amphora exca
P0002	NM0110	1	Pottery	Amphora	Chian	Intact chian am	F2-T1-T4-T6	0	01/06/2011	1	Lifted	a whole amph
P0002	NM0110	1	Pottery	Amphora	Chian	Intact chian am	F2-T1-T4-T6	0	20/05/2011	6	Monitored	Yellow tag, no
P0002	NM0110	1	Pottery	Amphora	Chian	Intact chian am	F2-T1-T4-T6	0	20/05/2011	7	Monitored	Attached stop
P0002	NM0110	1	Pottery	Amphora	Chian	Intact chian am	F2-T1-T4-T6	0	23/05/2011	3	Labelled	Tagged
P0002	NM0110	1	Pottery	Amphora	Chian	Intact chian am	F2-T1-T4-T6	0	31/05/2011	10	Moved	Excavated rea
P0002	NM0110	1	Pottery	Amphora	Chian	Intact chian am	F2-T1-T4-T6	0	13/06/2011	99	Labelled	Given museum
P0002	NM0110	1	Pottery	Amphora	Chian	Intact chian am	F2-T1-T4-T6	0	21/11/2007	1	Labelled	πλαστικός δισ

Figure 3. The Mazotos Shipwreck Database & Fieldwork Data production

As far as mapping is concerned, the method of Underwater Digital Photogrammetry has been applied daily during the excavation by the Photogrammetric Vision Lab of the Cyprus University of Technology. With this method accurate orthophotos were produced as can be seen in Figures 4 and 5 below.

Figure 4. Detail of the site, during photogrammetric acquisition (Skarlatos et al. 2010)

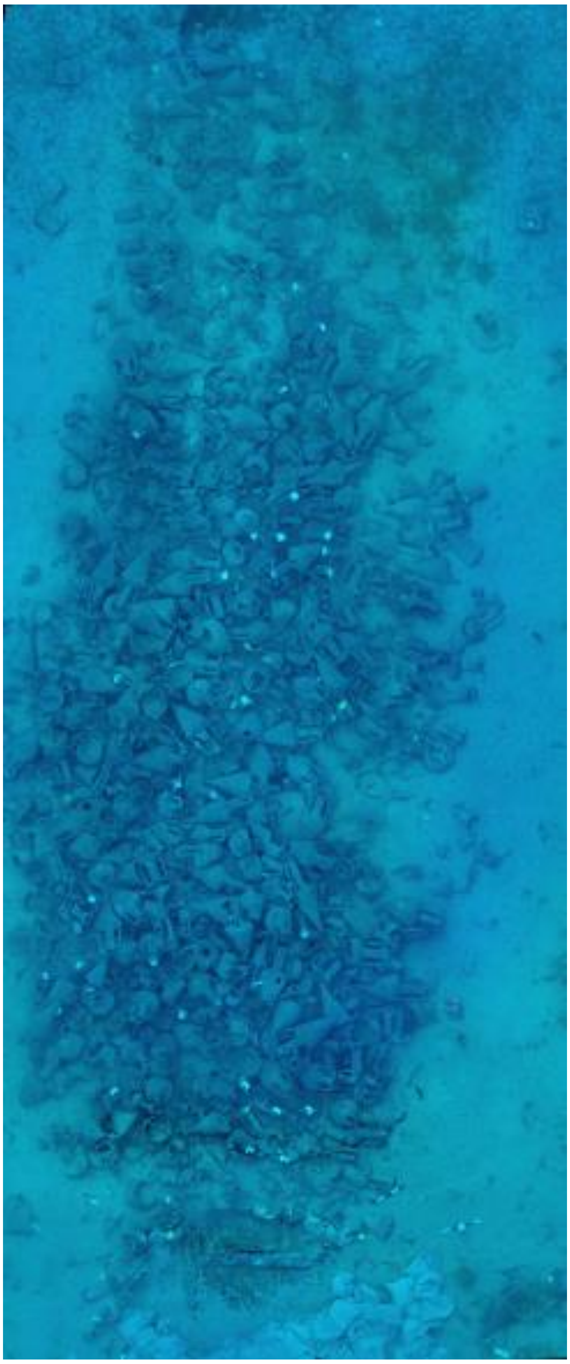

Figure 5. Orthophoto of the Mazotos ship-wreck (courtesy UCY, MARELab; CUT, Photogrammetric Vision Lab production: Skarlatos D. and Agrafiotis P.)

4. Methodology

The methodology used in the present study for the development of a GIS of Archaeological Information is based on archaeological data, the collection of which was made by field research, during the excavation periods at the Mazotos Shipwreck in Cyprus. The total volume of data from this multi-annual excavation is oversized. Therefore, it was decided to process only part of the Excavation Database for the Geographical Information System development process.

4a Archaeological data

The archaeological data that were selected were all amphorae (other types of finds also exist). The archeo-data were provided by the main organizer of the systematic excavation of the Mazotos Shipwreck, the Maritime Archaeological Research Laboratory (MARELab), University of Cyprus.

4b Geographical data

The GIS applications used the geographical data after their acquisition by Digital Photogrammetric Methods. All amphorae were saved as point entities and registered in a Geographic Data Base.

Furthermore, the purpose of the aforementioned Digital Photogrammetric mission was the surveying of the wreck as a whole, which was achieved during the excavation period of 2015. The orthophotos of the shipwreck originate from this same surveying season, which were provided, as well as the point entities. These particular orthographs have been the basis for the development of the GIS and have been introduced within ArcGIS computing environment.

Due to the fact that the managing a DB using a GIS, acts like a digital storage of many different data types (Agapiou et al. 2010), the most appropriate file type for this considered to be the MS Access. As a result, the amphorae were stored as point entities and registered in a Geographic Data Base in an Ms Access file format. Another advantage of the Ms Acces is that when connected to ArcGIS software is active while opened for editing data. So, for the implementation of any changes or registration of new objects, it permits to the user to view the additions or alternations instantly without a need to exit and reboot the software, a procedure followed for the MS Excel in order to visualize any changes or additions in the DB on the ArcGIS.

All the above georeferenced data were provided by the main collaborator of the project, the Photogrammetric Vision Lab, Cyprus University of Technology.

Moreover, the modelling of the Database Management System (DBMS), was defined as a Relational Database Management System (RDBMS). The basic relationship that occurs within this Relational Database is distinguished by the relationship one to many as the above descriptive data are recorded in Table, which are structured in such a way where multiple entries corresponding to many different tasks held for each amphora.

5. Purpose

The purpose of the development of the Geographic Data Base in this study is the management of archaeological findings, the extraction of archaeological information from an underwater archaeological site, a wreck in particular, for the essential coherence in the monitoring of the excavation process.

The aim of the study was to create a GIS compliant Database that includes all the necessary descriptive and geographic data mentioned above. The software chosen to fulfil this objective was ArcGIS, through the computing environment of which the data connection took place.

The most important task of this study was to act supportively and add value to the significant work that has been already done in the previous years. This study expedites procedures of managing and monitoring the data and archaeological information by gathering and combining all the data, geographic and descriptive; in this case the amphorae of the wreck are the only archaeological entities.

The purpose of the development of the application in this study is the management of archaeological findings, also to contribute in the necessary coherence for the monitoring of the excavation process, as well as the extraction of archaeological information from an underwater archaeological wreck site.

The system's end-users are the directors as well as the collaborators of the Mazotos Shipwreck Project, and, in general, the staff of the survey. In this way the designated personnel of the excavation will be able with ease to record the position of finds, to monitor and manage the execution of archaeological work for all the activities that concern an amphora and other objects or features of the shipwreck.

Another goal is the results to be visualized via high-resolution orthophotos into the GIS, as these form the basis of the local reference system of the site and are being used as maps during the progress of the excavation.

According to the archaeological GIS structure of Figure 6, the application mentioned in this paper intents to combine both the two main categories management and research. Therefore, it seeks to contribute to the management of the archaeological data as well as in research as it can be focused into an intra-site analysis of the data of the specific excavation leading to new outcomes.

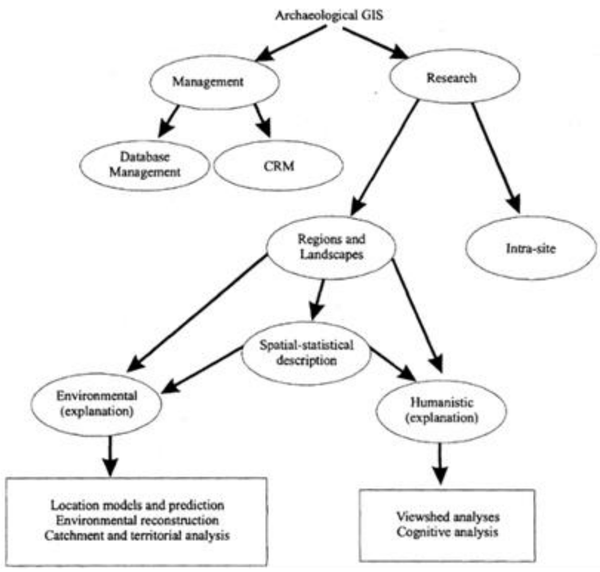

Figure 6. A suggested structure of the GIS applications within archaeology (Wheatley & Gillings 2002, fig. 12.1, p. 208)

6. Implementation

The procedure of the conceptual designing and logical development of the Database took also place for defining the entities and their interrelationships.

This was accomplished by designing a conceptual scheme. The design of the conceptual scheme of this paper follows in Figure 7.

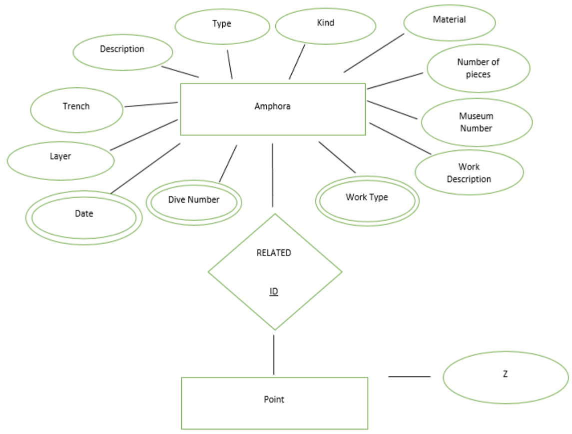

Figure 7. Conceptual Scheme Design of the study

Then, the next step was the design of the logical model, which is based directly on the conceptual model, the entities of which are modeled as tables. The fields correspond to their features and their relations with the other categories.

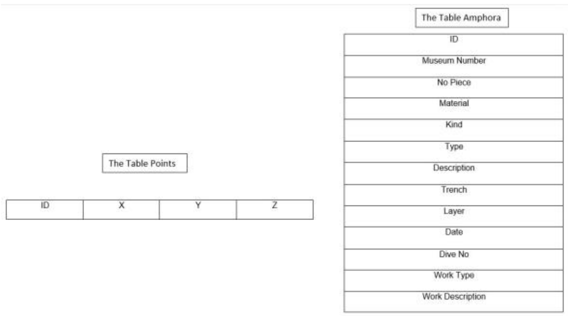

Figure 8. Logical Scheme Design of the study

6a Data

The data used in this study were: The archive with geographic data of the amphorae of the Mazotos Shipwreck. The format of the file was a code for each find and the X, Y, Z coordinates related to it. This file included data for 148 items. Moreover 19 orthophotographs in different days were provided, in order to cover the entire wreck site were used. Both the above were provided by the Photogrammetric Vision Lab of the Cyprus University of Technology.

Pottery finds from 2015 excavation season file, which lists, about 738 records of descriptive data in total, related to 145 amphorae provided by the Maritime Archaeological Research Laboratory (MARELab), University of Cyprus.

6b Data processing

After gathering the geographic and descriptive data, a pre-processing procedure of the files was held and were converted from their original type in order to be compatible with the ArcGIS software.

The pre- processing of the geographic data, which were in a txt file, included editing by transferring them, initially, within a MS Excel file (xls). In this xls file, 4 columns were created, which gave the corresponding ID, X, Y, Z data in the necessary fields, while listing the properties in the respective cells in each column. The properties consist of georeferenced points in columns along with an ID column which comprises a unique code file for each amphora find for the amphora-points relation.

This was done for organizing and counting the data, something that was achieved, as a difference of the 3 files in the number of amphoras between the two archives was identified, which then, as it turned out, was absolutely justified.

By organizing and re-measuring the geo-data those were able to be compared with the ones registered in the archaeological Database and spot the missing finds. This was also the case for the 3 files as 3 finds were previously lifted. Subsequently, a point shapefile was created with the above-mentioned ID, X, Y, Z fields. The spatial information table (xls) was connected with the shp file within the ArcMap.

The connection was performed on the basis of a common "key" field, in this study the ID field, through which the Database Management System "orientated" the transfer of records from one table to another.

As regards the archaeological data pre-processing this included the organization and re-measuring the raw descriptive material by checking the consistency of the data in relation with the geographical ones. This led the study to the generation of an Archaeological Data Base (mdb) in the MS Acces software. Furthermore, because the Database used both Greek and English language to describe data, for compatibility purposes all Greek words in the column titles were replaced by English.

Also, where necessary, the descriptive data were processed and separated from their previously merged format in the table to which they belonged for the needs of the underwater excavation archive. In this way, new attributes of descriptive data were created in the table of the New DB. The new categories of attributes, were Date and Dive columns.

Finally, all the archaeological data table were georeferenced as they were linked the geospatial ones via ArcMap JOIN command and again as common "key" the ID field.

7. Results

The above actions permitted this study’s DBMS system to run SQL queries, of spatial, temporal and archaeological nature. Visualization of the results was also possible through importing orthophoto maps into the ArcGIS graphic environment. Some examples are presented in the figures below. For example, "Which of the amphorae are Chian?"

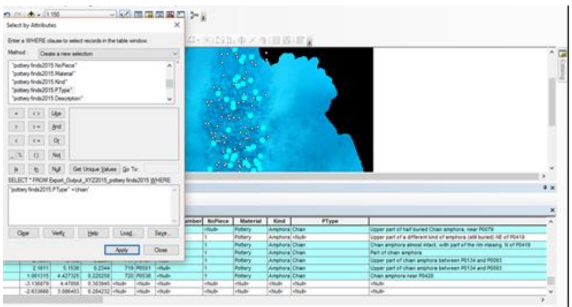

Figure 9. The visualization of the results in the graphic environment of the GIS to the query: "Which of the amphorae are Chian?"

Or as Figure 10 depicts: “Show me Moved amphorae" where colorful blue dot is showing all the amphorae assigned in the "Work Type" field as moved. A zoom in view of amphora P0051, which was moved at the side in order to be prepared to be lifted on the next dive.

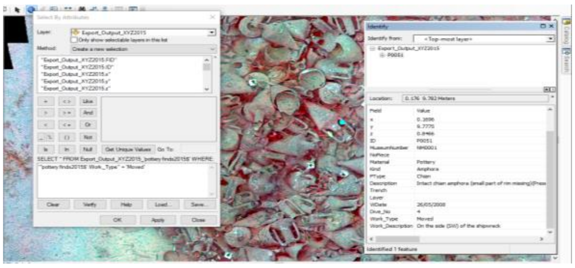

Figure 10. Detail of the query "Show me Moved amphorae" pointing moved amphora P0051 with a blue dot.

By combining spatial and archaeological data the system is able to illustrate the attributes with all the actions related to each amphora (e.g. the P0001 amphorae fig 13) with the relation one to many. In this way management of the archaeological data and intra-site focused search could be applied.

Moreover, the application is handling chronological information as an attribute when queries include the field Date (e.g. excavation tasks on 23.5.2012). In this specific study, time dynamics could be treated with a very simplistic time imaging strategy namely, by importing orthophotos of the corresponding excavation season.

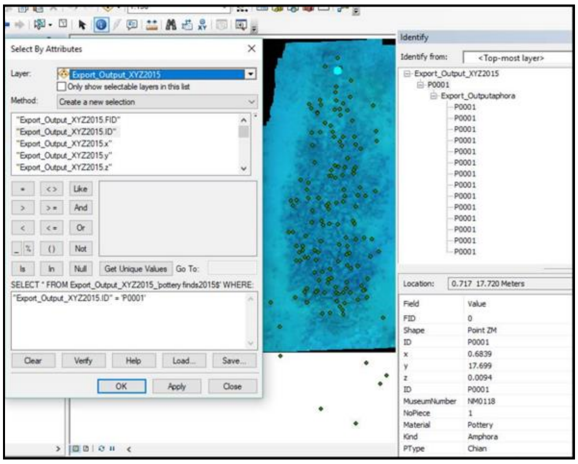

Figure 11. All the actions related to P0001 amphora

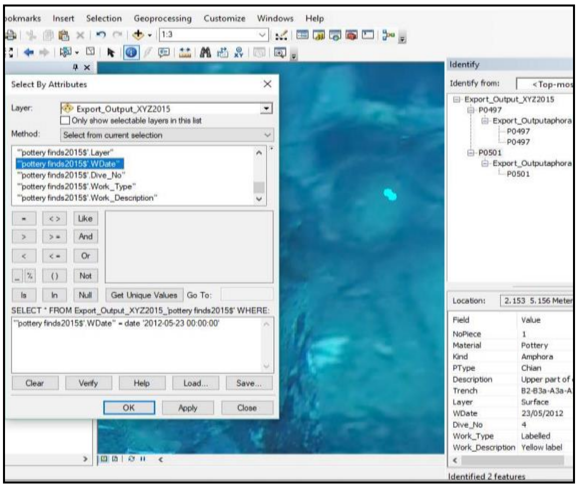

Figure 12. Spatio-temporal queries. Excavation tasks on the 23.5.2012

8. Conclusions and Evaluation

The GIS application presented in this paper enables answers to questions of archaeological nature. It showed many capabilities such as exploration, analysis, synthesis and presentation of results based on geoprocessing and geovisualization. The latter contributes in observation increase through realistic effects providing details of intra-site relations. Therefore, it has the potential to display and viewing new archaeological information. It gives also the ability to provide spatio-temporal queries as it was demonstrated above. However, this has to be done manually by importing the corresponding orhophoto map.

Additionally, a real-time archaeological data import and change-making in DBs within GIS is feasible. This can lead to a better control of the data volume and the number of actions and for an excavation management support. This could also serve as a tool of an active management and observation of the course of the excavation while this is being conducted. According to the archaeological data management retrieving older information related to an event or information about events related to an object could really be helpful.

The accuracy of the results and the reduction errors that can derive while working in a difficult underwater environment it could be considered something valuable.

At the end a GIS application of Archaeological information could have imported and combine different types of data and from different methods while at the same time reducing the time and cost of required monitoring during the survey.

Acknowledgements

Sincere thanks to Prof Stella Demesticha, director of the Mazotos Shipwreck excavation and the Maritime

Archaeological Research Laboratory (MARELab) of the University of Cyprus for the trust and provision of the necessary permissions for the use of the database and the related material of the Mazotos archaeological site excavation including the assignment of geographic data and orthophotographs.

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MAPPING ROMAN ATHENS

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Περίληψη

Η εργασία παρουσιάζει τις μεθοδολογικές κατευθυντήριες γραμμές και τις προκαταρκτικές φάσεις ενός έργου βασισμένου σε GIS που πραγματοποιείται στην Ιταλική Αρχαιολογική Σχολή Αθηνών, με κύριο στόχο την εξερεύνηση της Αθήνας του Παυσανία με ανακατασκευή των αστικών οδών που επέλεξε ο αρχαίος ταξιδιώτης να περπατήσει και να περιγράψει, τα μνημεία που είδε να στέκονται και το δομημένο περιβάλλον που διέσχισε. Το έργο κάνει αναφορά στην πλατφόρμα GIS που χρησιμοποιείται για την ανασυγκρότηση και την ανάλυση του αστικού πλαισίου της Ρώμης, τροποποιώντας την σύμφωνα με τα ιδιαίτερα αστικά χαρακτηριστικά της Αθήνας. Αποτελεί τμήμα της ευρύτερης προσπάθειας δημιουργίας μιας πλατφόρμας GIS αφιερωμένης στη Ρωμαϊκή Αθήνα, με στόχο την ανακατασκευή της πολεοδομίας της αρχαίας πόλης και την ανάλυση των χωρικών και κοινωνικών σχέσεων σε αυτήν. Ο συγκεκριμένος στόχος του έργου που παρουσιάζεται εδώ είναι να εξερευνήσει την Αθήνα του Παυσανία μέσα από τα μάτια του ταξιδιώτη, προσεγγίζοντας έτσι την διττή ερευνητική προοπτική: την ανακατασκευή του αστικού σχεδίου και την διάταξη των μνημείων της πόλης κατά την περίοδο του Αδριανού, καθώς και την «ιδανική» προσέγγιση του νοητικού χάρτη του αρχαίου ταξιδιώτη, χρησιμοποιώντας τόσο τα περιγραφικά δεδομένα του ίδιου του Παυσανία όσο και τα διαθέσιμα αρχαιολογικά στοιχεία.

Abstract

The paper presents the methodological guide-lines and the very preliminary phases of a GIS-based project carried out at the Italian Archaeological School of Athens, with the main aim to explore the Athens of Pausanias, by reconstructing the urban pathways which the ancient traveller chose to walk and to describe, the monuments that he saw standing and the built environment he crossed over. The project applies the GIS platform used for the reconstruction and analyses of the urban context of Rome (implemented by a La Sapienza University team to analyse the development of the city from the 9th C BC to the 6th C AD), modifying it according to the peculiar urban characteristics of Athens. It is part of the wider attempt to build up a GIS platform devoted to Roman Athens, aiming at the reconstruction of the ancient city layout and at the analyses on spatial and social relationships within it. The specific goal of the project presented here (led by Emeri Farinetti and Maria Chiara Monaco) is to explore Pausanias' Athens through the traveler's eyes, approaching this way a twofold research perspective: the reconstruction of the urban plan and the layout of the monuments of the city in the Hadrian period, as well as the ideal approaching to the ancient traveler's mental map, employing both the legacy data he left us and the archaeological record available.

Λέξεις Κλειδιά/Keywords: Mental maps, GIS, city-scapes, mapping ancient sources, Pausanias.

1. Introduction

The paper presents the methodological guide-lines of a GIS-based project carried out at the Italian Archaeological School of Athens, with the main aim to explore the Athens of Pausanias, by reconstructing the urban pathways the ancient traveller chose to walk and to describe, the monuments that he saw standing and the built environment he crossed over. We will illustrate the main characteristics of the information system employed, and the processes of data-building involved in this preliminary phase of the project.

The project applies the GIS platform used for the reconstruction and analyses of the urban context of Rome (implemented by a La Sapienza University team to analyse the development of the city from the 9th C BC to the 6th C AD), modifying it according to the peculiar urban characteristics of Athens, and it is part of the wider attempt to build up a GIS platform devoted to Roman Athens, aiming at the reconstruction of the ancient city layout and at the analyses on spatial and social relationships within it.

2. The digital Atlas of the City of Rome

The Digital Atlas of Rome project started twenty years ago with the aim of reconstructing the evolution of the landscape of the city of Rome and its *suburbium*. The approach is systematic, contextual and diachronical, and the project developed as GIS-based since the beginning. Main goal is to map and analyse the remains of the urban and monumental layout of the city, enhancing the contextual connections which, although broken and disconnected through time, can be joined together again in order to reconstruct and interpret the original city-scapes and architecture, and to trace the city landscape narrative (figs.1-3).

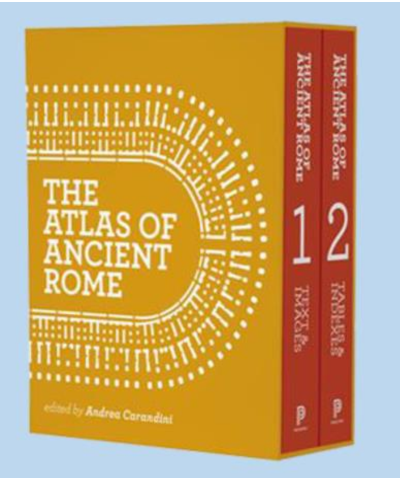

Figure 1. The Atlas of Ancient Rome Biography and Portraits of the City (2017), A. Carandini ed.

As key features of the archaeological analysis aiming at the reconstruction of the built environment within which ancient people lived, archaeological finds at different levels are involved, from the large Ulpian basilica till a small Republican honorary statue.

Strong attention is paid to the creation of detailed vector shapes, representing all the structures and some finds discovered up to now (including building and wall decorations, statues and inscriptions), mapped in real absolute coordinates and not-symbolic (figs.2-4)

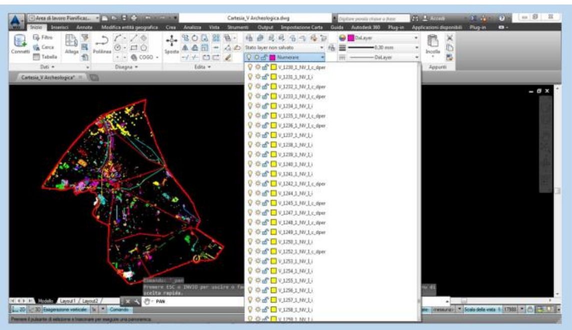

Figure 2. Rome. Regio V (Esquiliae) Archaeological map (Autocad environment linked to a PostGres DB).

Figure 3. Period map - Regio IX (Circus Flaminius)

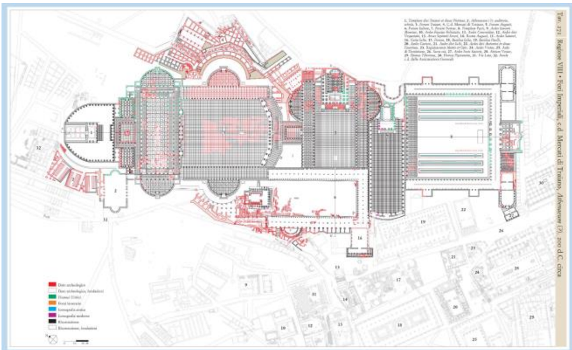

Figure 4. Reconstructed map of the Imperial Fora area (Rome), with the reconstruction layers clearly visible.

Vector layers were initially produced in AutoDESK environments, and were later joined with a PostGRES relational database. The large geographical archive was then moved to an ESRI environment for analyses and thematic mapping to get finally into a WEB interface to disseminate the data to the larger public.

3. Towards a digital Atlas of the City of Athens

The Italian Archaeological School at Athens is working on the creation of an Atlas of Roman Athens, based on the model applied in Rome, joining

PostGRES relational databases within a GIS environment, with the help of AutoDESK products to produce digital data and create 3D models. Some spatial analyses are carried out in QGIS.

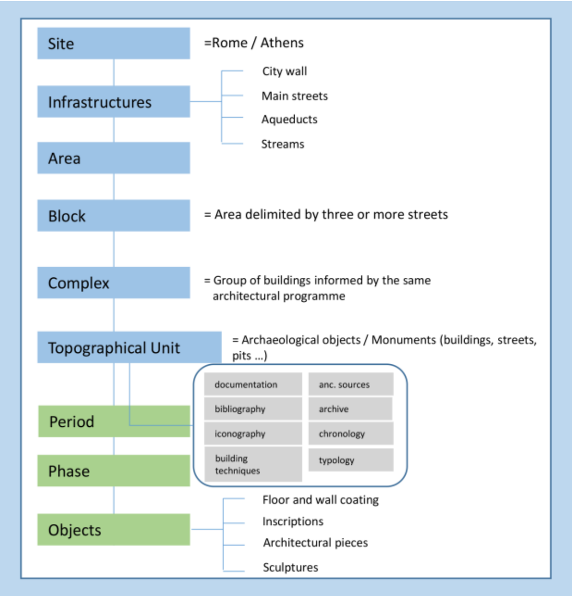

Figure 5. Conceptual model of the digital Atlas of ancient Rome and Athens.

The project aims to manage the various and heterogeneous sources of information which, collected and analysed, would allow to re-construct and re-build the landscape and built environment's contextual links, often interrupted by human and natural actions through time.

This will provide for the systematic collection - so far never attempted - of all the archaeological evidence datable to the Roman period, or still standing in that time span, found in the Greek capital within the walls and the immediate surroundings (as an example, we may refer to the Plato's Academy founded in 387 BC and located north-west of the inhabited city).

The approach is diachronical and multilevel, dynamic and flexible, in order to deal with urban contexts with highly complex stratification, and to enhance variability in the city-scape in Greco-Roman antiquity.

By analysing each piece of evidence, or unit of archaeological evidence, in terms of environmental context and cultural/historical landscape, we can proceed to a progressive logic-spatial process of the known evidence, at different levels.

On the basis of the collected data, and their mutual spatial and contextual relationships, reconstruction hypotheses will be proposed. Different classes of 'documents' will be employed to enhance the quality of the reconstruction, through a constructive source-critique which would allow to reach incremental levels of plausibility and reasonableness.

The goal is twofold:
- to recompose a unitary and global framework of available knowledge based on different sources of information that allows to analyze and systematically investigate what is known and what is little or poorly known;

- to propose reconstructive hypotheses, based on all the different classes of documents that allow to integrate the little or poorly known parts of the ancient monuments, to try to define hypotheses about the lost or missing parts of what is known, in search of a progressive plausibility.

Separate layers are created for the various reconstruction hypotheses, integrated to the actual remains record, allowing for the definition of hypotheses to be separated from, although linked to, more objective row data. The work, still at its initial stage, had a significant starting point with the production of the relevant GIS layers employed in the mapping process for the published volume HADRIANUS-Αδριανός (Λαγογιάννη - Papi 2018; fig.6).

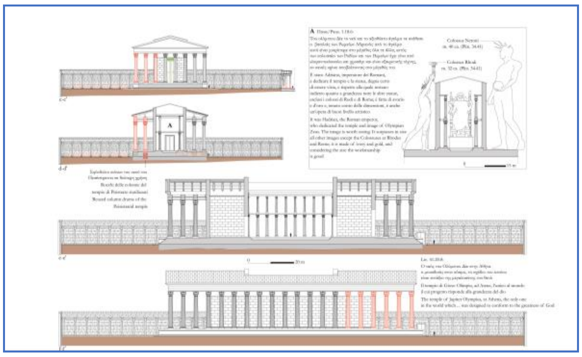
Figure 6. *Olympieion*, reconstruction profiles (Λαγογιάννη - Papi 2018).

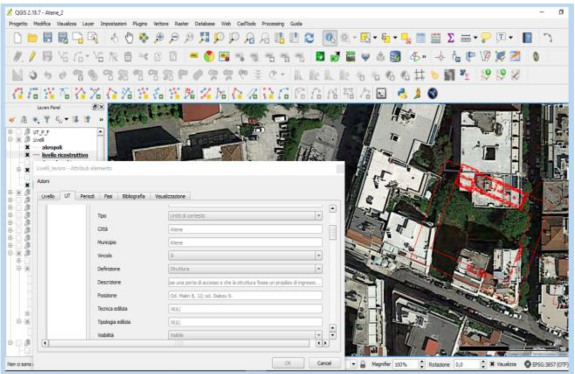
Figure 7. Athens. The so-called 'lowcourt *επί* Παλλαδίω'

4. Towards a digital approach to Pausania's journey in Athens, between description and experience

In the same GIS framework dealing with Roman Athens a particular attention will be given to the city-scape of the ancient *periegetes* travelling in Greece (and Athens) during the 2nd century AD.

The immediate next step of the project presented here is to explore Pausanias' Athens through the traveler's eyes, approaching this way a twofold research perspective: the reconstruction of the urban plan and the layout of the monuments of the city in the Hadrian period, and the ideal approaching to the ancient traveler's mental map, employing both the legacy data he left us and the archaeological record available. Specific metadata, involving both these data-set frameworks, will be involved in the processes of data collection and analyses.

Two main goals will be pursued:

- to describe and recostruct in 2D and 3D maps the real city in Pausanias' times, along with the itinerary through the city-scape.
- to approach Pausania's perception of the city by examining his choices in his description, as for content and form/style.

As basis for the achievement of the first goal the map layers of the Atlas of Roman Athens will be used. In it will be included also the buildings and monuments from the Classical city and earlier periods mentioned by the Traveler, as included in the volumes on the topography of ancient Athens published by the Italian School of Archaeology at Athens (SATAA 1.1/1.2/1.3/1.4).

At the end, real and mental maps of Pausania's travel through Athens will be produced, focusing both on the reconstruction of the whole set of standing monuments in the Athens of the 2nd century and on the buildings and monuments that the Traveler chose to pay attention to and to describe. The routes within the city will be enlightened, to evaluate Pausania's virtual and/or real choices.

Fig.8 illustrates the conceptual model which will be used to record and analyse the Pausania's city-scape, the Traveler's movement and his narrative choices in description, within an integrated GIS and DB management system. Entities included in the system are: the standing monuments mentioned by the Traveler, the standing monuments visible in the city-scape but not mentioned in Pausania's text, the monuments which were out-of-use in Pausania's time but are mentioned in the text. All the entities are along paths (reconstructed on the basis of the ancient city street network) and can be linked to movable objects mentioned by the author in connection with them. Textual entities (such as philological gaps, excursus) are also included in the data model, in interrelation with the monuments themselves and the Pausania's description of them. Spatial connectors and movement in space are instances taken into account in the system.

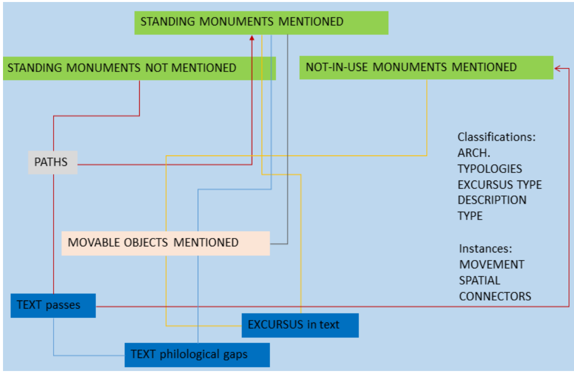

Figure 8. Conceptual model of the real and mental map of Pausania's travel through the Athens of the 2nd C AD.

In particular, the spatial connectors used in the text, along with their meaning and occurrence, employed by Pausanias to describe the spatial relationships between the monuments mentioned and described, can give us an idea of the real and mental distances between different entities as well as of the perception of the city-scape the ancient traveller had.

Furthermore, the analysis of proximity in space and time, in Pausania's description, would allow us to get an idea of Pausanias's movement through the city, but also can help us understand his choices and meaningful absences in the text. A significant differentiation is made between the degree of proximity of features/monuments in the real world and the degree of proximity of the same features in Pausania's text, verbalised through spatial connectors (fig.9).

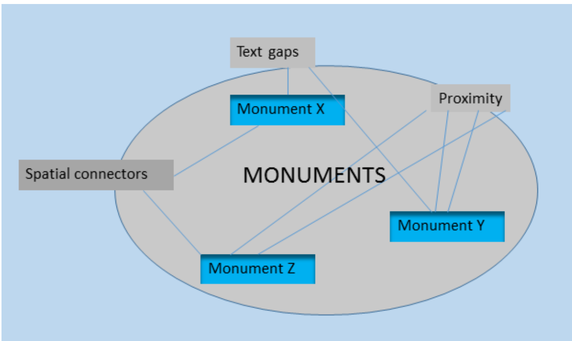

Figure 9. A dense network of monuments, places, words and connections in the mental map of Pausania's Athens.

The Pausania's application is still at his initial stage, as for textual analysis and recording as well as for features mapped and routes detection. The analytical stage will immediately follow, and we believe that it will benefit from the project's inclusion in the wider methodological framework of the large Atlas of the city of Rome and of Roman Athens, illustrated above.

Class	Greek - definition	location	Greek phrasing
H	παρθένοι δύο [...] οἰκοῦσιν οὐ πόρρω, καλοῦσι δέ Αθηναιοι σφᾶς αρρηφόρους	not far from the Athena's temple	οὐ πόρρω
B	περίβολος	not very far away	οὐ πόρρω
H (underground passage)	χαλκοῦν	below the Aphrodite's themenos	δι΄αὐτοῦ
F	†εὐήρις	by Athena's temple	πρός δέ
F	ἀγάλαμτα μεγαλα χαλκοῦ [...] τόν μέν Ερεχθέα καλοῦσι	by Athena's temple	ἔστι δέ
F	ἀγάλαμτα μεγαλα χαλκοῦ [...] τόν δέ Εὔμολπον	by Athena's temple	ἔστι δέ
FF	ἀνδριάντες εἰσί Θεναίετος [...] καί αὐτός Τολμίδες	on the same base	ἐπί δέ τοῦ βάθρου
FF	Ἀθηνᾶς ἀγαλματα ἀρχαια		
F (group)	συός δέ θήρα		
F (group)	εἰκών	on the Acropolis	ἐν ἀκποπόλει

Figure 10. Examples of objects listed in Pausania's description of Athens, as they are recorded in the system.

Acknowledgements
The authors gratefully thank the director of the Italian Archaeological School at Athens, Prof. Emanuele Papi, who suggested the need of such kind of work, the équipe of the Digital Atlas of Rome from La Sapienza University, and Prof. Maria Chiara Monaco, involved in the philological and archaeological reading of Pausania's text in order to address correctly all the information available and the research issues behind this project.

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MONITORING CULTURAL HERITAGE SITES AFFECTED BY GEO-HAZARDS USING IN-SITU AND SAR DATA: THE CHOIROKOITIA CASE STUDY FOR THE PROTHEGO PROJECT

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Περίληψη

Το έργο PROTHEGO (PROTection of European Cultural HEritage from GeO-hazards) (Προστασία Πολιτιστικής Κληρονομιάς της Ευρώπης από γεωλογικούς κινδύνους) χρησιμοποιεί καινοτόμες διαστημικές τεχνολογίες για την παρακολούθηση των περιοχών πολιτιστικής κληρονομίας από γεωλογικούς κινδύνους για την ανάλυση των περιβαλλοντικών συνθηκών και την παρακολούθηση των γεωλογικών αλλαγών με ακρίβεια χιλιοστών.

Το έργο ‘PROTHEGO’ θα προσφέρει ένα νέο εργαλείο καθώς και μια νέα χαμηλού κόστους μεθοδολογική προσέγγιση για τη διαχείριση των χώρων και μνημείων παγκόσμιας πολιτιστικής κληρονομιάς που βρίσκονται σε όλη την Ευρώπη, χρησιμοποιώντας εξειδικευμένες τεχνικές τηλεπισκόπησης. Περιοχές μελέτης θα απολέσουν τα 395 μνημεία της UNESCO σε όλη την Ευρώπη. Η προτεινόμενη μεθοδολογία του PROTHEGO αφορά συστήματα παρακολούθησης σε μακροπρόθεσμη βάση, έμμεση ανάλυση των περιβαλλοντικών συνθηκών, την έρευνα των αλλαγών και την αποσύνθεση της δομής, το υλικό, και τον περιβάλλοντα χώρο των μνημείων Πολιτιστικής Κληρονομιάς. Η μεθοδολογία του έργου με την παρακολούθηση την πολιτιστικής κληρονομίας με δεδομένα radar (SAR) όπως και η πλατφόρμα GIS είναι χρήσιμα εργαλεία για τους υπεύθυνους χάραξης πολιτικής στον τομέα της πολιτιστικής κληρονομιάς για να χρησιμοποιηθεί για τη σωστή λήψη αποφάσεων με βάση την ολοκληρωμένη αξιολόγηση των κινδύνων. Η πρωτοποριακή χρήση των τεχνολογιών, όπως των αυτόνομων συστημάτων πλοήγησης (UAVs) επιτρέπει μια πραγματική τρισδιάστατη ανακατασκευή του χώρου και ταυτόχρονα τη δημιουργία εικονικών μοντέλων. Παράλληλα στο έργο χρησιμοποιούνται δορυφορικά πολυφασματικά δεδομένα και δεδομένα radar (SAR) για την παρακολούθηση των μνημείων.

Abstract

PROTHEGO (PROTection of European Cultural HEritage from GeO-hazards) uses novel space technology or the detection and monitoring of European Cultural Heritages exposed to natural hazards, namely monuments and sites potentially unstable due to landslides, sinkholes, ground settlement, active tectonics as well as monument deformation, all of which could be affected by climate change and human interaction. The project includes the 395 monuments of UNESCO in Europe to monitor geo-hazards, with case studies conducted in 4 UNESCO sites in England, Spain, Italy and Cyprus.

PROTHEGO provides a new, low-cost methodological approach for the safe management of cultural heritage monuments and sites located in Europe, by integrating novel space technology based on long-term low-impact monitoring systems, such as UAVs and geodetic techniques, radar interferometry (InSAR) systems and indirect analysis of environmental contexts to to monitor and assess the risk of geo-hazards in the 400+ UNESCO's World Heritage List monuments and sites of Europe

This paper will present an overview of the monitoring techniques using in-situ and Earth observation for Cultural Heritage monuments sites affected by geo-hazards that are potentially unstable due to landslides, sinkholes, settlement, subsidence, active tectonics as well as structural deformation.

Λέξεις Κλειδιά/Keywords: Cultural heritage, natural hazards, remote sensing, UAV, geodetic techniques, JPI

1. Introduction

In the past decades, it was widely recognized that cultural heritage can be highly vulnerable to geological disasters induced by earthquakes, volcanoes, floods and catastrophic landslides. As well, cultural heritage is vulnerable to other non-catastrophic slow-onset geohazards that can slowly affect the integrity and accessibility of the heritage, such as slow-moving landslides, sinkholes, ground settlement and active tectonics. Even if these phenomena can be responsible for large damages, they are largely neglected in the literature (Gutiérrez and Cooper, 2002; Rohn *et al*, 2005; Canuti *et al*, 2009). The long-term vulnerability of cultural heritage is commonly focused on the heritage itself (i.e., degradation and corrosion of building materials) in response to environmental risks (Brimblecombe, 2000; Fort *et al*, 2006), without fully considering or understanding the entire geological and geotechnical context. Currently, assessing geo-hazards in cultural heritage sites takes place after the geo-hazard has occurred. However, the high costs of maintenance of cultural heritage sites directly enforce the prioritisation of the monitoring and conservation policies to ensure sustainable conservation. Monitoring the deformation of structures as well as their surroundings facilitates the early recognition of potential risks and enables effective conservation planning (Tang *et al* 2016).

On-site observation has been the most common way of monitoring cultural heritage sites and monuments in Europe. However, this procedure, that includes field surveying, ground-based data collection and periodical observations, can be time consuming and expensive, especially over large or remote areas is extremely difficult, expensive and time consuming. (Themistocleous *et al*, 2016a). Traditionally, deformation monitoring in cultural heritage sites is carried out by installing electrical sensors in selected structures with automatic systems for data acquisition and recording or by using portable instruments with manual reading of data taken at fixed time intervals (Zhou *et al*, 2015; Garziera *et al*, 2007; Glisic and Inaudi, 2008). However, such methods can only acquire data of the monitored structure within the cultural heritage sites, not the entire area of the site and its surrounding landscape (Zhou *et al*, 2015). Moreover, the installation of monitoring devices, such as optical targets, permanent GNSS stations or inclinometers, on the heritage sites and monuments can lead to aesthetic and functional impacts that can affect the integrity and availability of the heritage.

The aim of the PROTHEGO project (www.prothego.eu) is to develop and validate an innovative multi-scale methodology for the detection and monitoring of European Cultural Heritages exposed to natural hazards, namely monuments and sites potentially unstable due to landslides, sinkholes, ground settlement, active tectonics as well as monument deformation, all of which could be affected by climate change and human interaction. PROTHEGO provides a new, low-cost methodological approach for the safe management of cultural heritage monuments and sites located in Europe, by integrating novel space technology based on radar interferometry (InSAR), long-term low-impact monitoring systems and indirect analysis of environmental contexts to retrieve information on ground stability and motion in the 400+ UNESCO's World Heritage List monuments and sites of Europe (Margottini *et al*, 2016; Themistocleous *et al*, 2016a).

2. Study Area

The field monitoring is being conducted at the UNESCO World Heritage Site of Choirokoitia in Cyprus, which is one of the four demonstration sites of the PROTHEGO project. The Neolithic settlement of Choirokoitia, occupied from the 7th to the 4th millennium B.C., is one of the most important prehistoric sites in the eastern Mediterranean (UNESCO). Included in the UNESCO World Cultural Heritage list since 1988, Choirokoitia is one of the best preserved settlements of this period in Cyprus and the Eastern Mediterranean. Located in the District of Larnaka, about 6 km from the southern coast of Cyprus, the Neolithic settlement of Choirokoitia lies on the slopes of a hill partly enclosed in a loop of the Maroni River. Occupied from the 7th to the 5th millennium B.C., the village covers an area of approximately 3 ha at its maximum extent and is one of the most important prehistoric sites in the eastern Mediterranean. It represents the Aceramic Neolithic of Cyprus at its peak, that is the success of the first human occupation of the island by farmers coming from the Near East mainland around the beginning of 9th millennium.

Figure 1. Choirokoitia, Cyprus.

Since only part of the site has been excavated, it forms an exceptional archaeological reserve for future study. To date, 20 houses have been excavated which were constructed with limestone, clay and brick. The site depicts how people lived in the Neolithic era which was mostly through agriculture and raising domestic animals. According to UNESCO the site was officially abandoned in the 4th millenium BC. The reason for this still remains unknown (UNESCO).

3. Monitoring Geo-Hazards

According to Margottini *et al*, (2015), the combined adoption of different survey techniques, such as 3D laser scanning and ground-based radar interferometry may be the best solution in the interdisciplinary field of cultural heritage preservation policies. Satellite radar interferometry is capable of monitoring surface deformation with high accuracy using precise ground measurements. Once vulnerable sites are identified by InSAR satellite imagery, local-scale monitoring and advanced modeling can be used to monitor the cultural heritage sites over time. The locale scale monitoring methodology includes in-situ observation and remote sensing techniques, such as PS techniques, that are used to validate the impact of natural hazards. Topographic surveying using differential GNSS, Unmanned Aerial Vehical (UAV) images, photogrammetry and InSAR data are used to map slow ground movements, which are then compared and validated with ground based geotechnical monitoring in order to evaluate cultural heritage sites deformation trend and to understand its behaviour over time. As a result, areas exposed to potential risks and their evolution in time can be identified and crucial information can be provided to decision makers in order to protect cultural and heritage sites from natural hazards.

Locale scale monitoring provides the opportunity to detect and analyze deformation phenomena for monitoring and predicting geo-hazards using field survey techniques to measure and document the extent of damage of the natural hazard on the cultural heritage site. The geodetic techniques can be used in combination with UAVs for documentation purposes and 3D modeling comparison. The aerial imagery obtained from the UAVs can be imported into Structure in Motion software to create rapid and automated generation of a point cloud model and 3D mesh model in order to document and monitor the extent of geo-hazards at the cultural heritage site. The ground based geotechnical monitoring can then be compared and validated with InSAR data to evaluate cultural heritage sites deformation trends.

Local scale monitoring can be used to assess the severity of these geo-hazards by using integrated field monitoring techniques. Research indicates that the integration of InSAR data and conventional surveying offers the best solution for monitoring geo-hazards in cultural heritage sites (Margottini *et al*, 2015; Novellino *et al*, 2018; Margottini *et al*, 2018). Geotechnical techniques are used to measure deformation over a relatively short measurement base. In-situ measurements using UAV, total station, laser scanning and GPS are then used to further measure such movements. In order to document the cultural heritage site affected by geo-hazards, UAV images and laser scanning are used (Themistocleous 2017; Themistocleous *et al* 2017a; Themistocleous *et al* 2017b).

For the PROTHEGO study, a methodology was developed for local-scale monitoring in order to assess the risk from natural hazards on the archaeological sites and monuments from a geospatial perspective. The research methodology focused on long-term low-impact monitoring systems as well as indirect analysis of environmental contexts to investigate changes and decay of structure, material and landscape (Themistocleous *et al*, 2016a; Themistocleous, 2018). In addition, a multi-criteria analysis of the UNESCO sites in Cyprus to estimate the severity of each geo-hazard (Silvestrou and Themistocleous, 2018).

The methodology for the locale scale monitoring begins with using InSAR images to identify natural hazards in the UNESCO World Heritage demonstration sites. When the InSAR ground motion data indicate that a natural hazard took place at or near the demonstration site, field monitoring and verification is necessary to document and measure the extent of the change caused by the natural hazard, if any. Documentation of the damage can be performed either close range, using laser scanning or photogrammetry, or by low altitude sensors, using UAVs and drones. Measurements for calibration of these products are taken using GNSS and total station. After the change is identified using field verification, InSAR images are again used to verify and assess the extent of the damage to the cultural heritage site (Themistocleous *et al*, 2018c). The methodology is presented in figure 2.

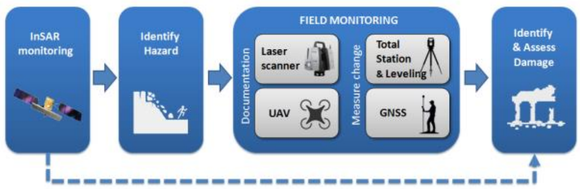


Figure 2: Methodology

3a Satellite Imagery

By examining vast regions of interest from 800 km above the Earth's surface, Synthetic Aperture Radar (SAR) imaging satellites, Interferometric SAR (InSAR) and Persistent Scatterers (PS) processing techniques (Rosen *et al*, 2000; Ferretti *et al*, 2011; Crosetto *et al*, 2010) are capable of estimating, with up to millimetre precision, subtle and non-catastrophic, long-term and seasonal land processes that are triggered by a variety of natural and anthropogenic causes and drivers that can cause damage to the tangible heritage. Once vulnerable sites are identified by InSar, detailed geological interpretation, hazard analysis, local-scale monitoring, advanced modeling and field surveying for the most critical sites will be carried out to discover cause and extent of the observed motions.

Satellite Synthetic Aperture Radar (SAR) images acquired by active radar sensors are processed with multi-interferogram methods – such as the Persistent Scatterers (PS) and used to extract information on ground displacement occurred across the areas of interest during the monitoring period, thereby providing an effective solution to measure large-scale surface deformations from space (Zhou *et al*, 2015; Ferretti *et al*, 2011; Hooper *et al*, 2012; Chen *et al*, 2013; Chen *et al*, 2012; Cigna *et al*, 2012; Cigna *et al*, 2014).

3b Unmanned Aerial Vehicles (UAVs)

UAVs have become a common tool in cultural heritage and archaeological research as they provide higher resolution images compared with satellite imagery. Remote sensing technologies on a UAV platform are extremely useful for the detection and monitoring of cultural heritage features (Themistocleous *et al*, 2014a; Themistocleous *et al*, 2014b; Themistocleous *et al*, 2014c; Agapiou *et al*, 2013). UAVs can be a efficient, non-evasive and low cost resource to document cultural heritage sites (Themistocleous *et al*, 2014a; Themistocleous *et al*, 2014b; Themistocleous *et al*, 2014c; Agapiou *et al*, 2013) and can be fitted with sensors which are able to produce an unprecedented volume of high-resolution, geo-tagged image-sets of cultural heritage sites from above (Themistocleous *et al*, 2014a; Themistocleous *et al*, 2014b; Kostrzewa *et al*, 2003; Ruffino and Moccia, 2015; Scholtz *et al*, 2011).

UAVs provide an affordable, reliable and straightforward method of capturing cultural heritage sites, thereby providing a more efficient and sustainable approach to documentation of cultural heritage sites. (Themistocleous *et al*, 2015a; Themistocleous *et al*, 2015b; Themistocleous *et al*, 2015c; Lo Brutto *et al*, 2014; Burkhart *et al*, 2014; Colomina and Molina, 2014). Recent developments in photogrammetry technology provide a simple and cost-effective method of generating relatively accurate 3D models from 2D images (Ioannides *et al*, 2013; Themistocleous *et al*, 2015a; Themistocleous *et al*, 2015b; Themistocleous *et al*, 2014a; Themistocleous *et al*, 2015c). To document cultural heritage site under threat from geo-hazards, UAV images can be used to create ortho-photos, dense clouds, 3D model and Digital Elevation Models (Themistocleous, 2017). The UAVs should be equipped with a 20mp camera to acquire images over the site with fixed ground control points for geo-referencing in order to produce a photogrammetric ortho-image and point cloud 3D model of the demonstration site and also for comparison over temporal intervals.

3c Laser Scanners

Laser scanners have become increasingly efficient in terms of point acquisition speed, portability, user friendly and cost (Fassi *et al*, 2013). Laser scan technology allows user to produces a high-precision digital reference data that records condition, provides a virtual model for replication, and makes possible easy mass distribution of digital data (Vilceanu *et al*, 2015; Hassani, 2015) of the cultural heritage site. Site documentation can be conducted using a laser scanner to monitor the site so that comparison over temporal intervals will be performed. The laser scanner cloud point can be used for further 3D modelling of the area and to generate a Digital Surface Model (DSM) of the site.

3d Surveying techniques

For the local-scale monitoring, surveying techniques are used to determine the absolute positions and positional changes of any point on the surface and geotechnical techniques to measure deformation over a relatively short measurement base. Surveying techniques, such as total station, leveling, and Global Navigation Satellite Systems (GNSS), are used to measure the positional changes of any point on the surface at millimeter level accuracy. They have also been successfully used for measuring deformations in archaeological areas affected by hazards (Polcari *et al*, 2015; Fassi *et al*, 2013; Jiang *et al*, 2012). GNSS provides location coordinates in global geographical system, highly useful in combination with other techniques, being appropriate in documenting mass targets and structural deformation (Hassani, 2015). Electronic data collection with total station instruments permits the quick acquisition of large amounts of field data, together with the efficient and error-free transfer of the data to a computer (Haddad, 2011).

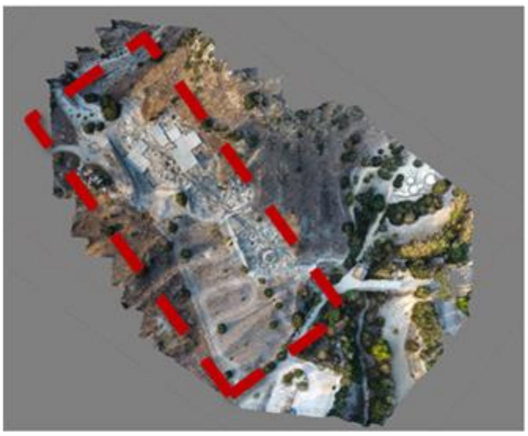
3e Geodetic techniques

A geodetic network consists of a reference point and additional nodes, established at specific points of interest (i.e. points on peaks or ridges that may indicate/warn of a potential hazard) (Themistocleous *et al*, 2017a; Themistocleous *et al*, 2017c). Network points are measured regularly using satellite (GNSS) and ground measurements (via high precision total stations and levels) to estimate the potential relative motion with respect to the network reference point, during the life-span of the monitoring activity. The number of points is a function of site vulnerability parameters as indicated by geology specialists. The network nodes (or control points) need to be incorporated into the site and placed in such way as to ensure mutual visibility with the total station setup at the reference point (Themistocleous *et al*, 2017a; Themistocleous *et al*, 2017b). There are various GNSS units that can be used to establish the geodetic network. The Trimble Zephyr 2 GNSS and Leica GS15 Smart GNSS Receivers are recommended for establishing a GNSS control network. Horizontal displacements can be measured using an industrial-grade total station while vertical motion can be measured using a high-precision digital level. (Themistocleous *et al*, 2017a; Themistocleous *et al*, 2017b).

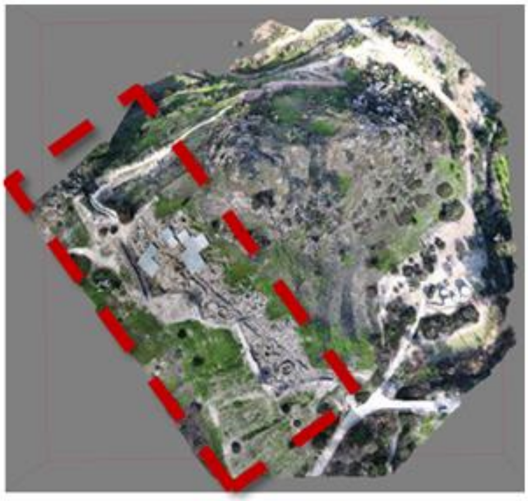
4. Results

In order to support field monitoring, geometric documentation of the area is performed using a laser scanner, UAV systems and photogrammetry. This data will be supported and geo-referenced using a geodetic network based on total station and level measurements. The focus of the documentation is the reconstruction of the cross-sections over the identified areas of the demonstration site in order to investigate possible changes in the vertical and horizontal profiles of the remains. Under the framework of the PROTHEGO project, hundreds of images of the Choirokoitia site were taken using a UAV with an attached high resolution camera. As part of the locale-scale monitoring of the Choirokoitia demonstration site in the PROTHEGO project, a UAV with an attached 20MP camera was used to acquire images over the site with fixed ground control points for geo-referencing in order to produce a photogrammetric ortho-image of the demonstration site and also for comparison over temporal intervals. The images were processed using photogrammetry, where the digital images acquired from the UAV are interpolated in order to create high resolution, scaled and georeferenced 3-D models from them.

Images were taken using UAVs on 29 October, 2016, 2 February, 2017, 11 November and 8 March, 2018, with approximately 450 images taken of the Choirokoitia site during each UAV flight. Ground Control Points (GCP) were applied to correct the scale and geo-reference the model. The images were then pre-processed by removing the lens distortion and then processed using the Agisoft Photoscan Professional software.



29 October, 2016



2 February, 2017

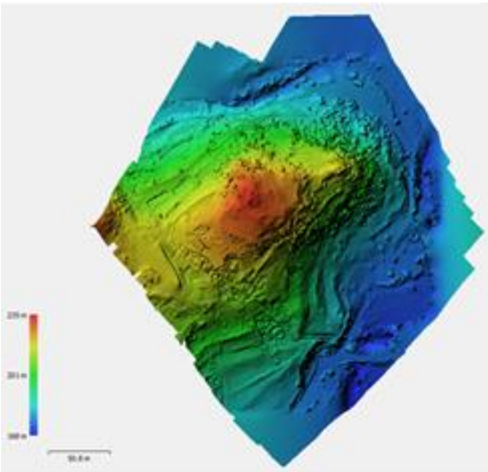
11 November, 2017

7 March, 2018

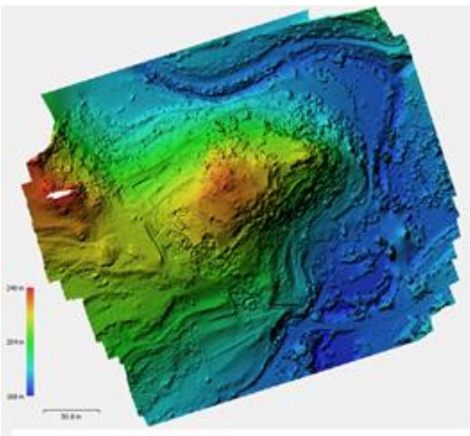
Figure 3. Point cloud generations of Choirokoitia site (outlined in red)

As is evident from Figure 3, there was a dramatic difference in the level of vegetation present at the site on the dates that the images were acquired. The October 2016 and November 2017 images show sparse vegetation while the images acquired in February 2017 and March 2018 show significantly more vegetation present at the site. As it was easier to identify vegetation in the images acquired in the winter campaign due to the colour and morphology of the vegetation, masking was done in order to subtract the vegetation from the model in order to generate the DEM of the ground surface. This was done by using interpolation of the areas where the vegetation was previously present using the images acquired in October, 2016 and February 2017.

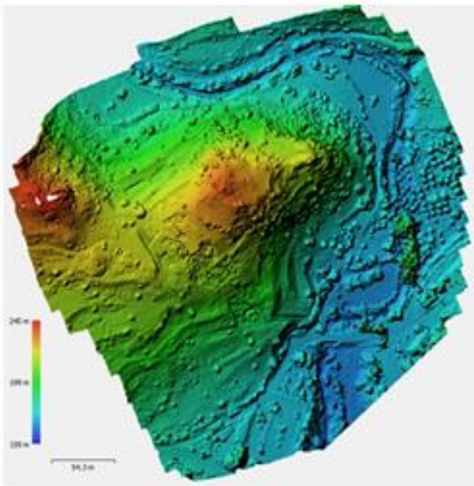
Following, a contour map of the area was generated using stitch imaging using the DEM model without vegetation. Digital Elevation Models (DEMs) were generated to examine any possible changes in the case study area over time. Figure 10 features the DEMS generated based on the images from February, 2017, November, 2017 and March, 2018. As is evident, there is a slight shift at the top peak of the hill.



2 February, 2017



11 November, 2017



7 March, 2018

Figure 4. DEM models of the Choirokoitia site

The final 3D model of the Choirokoitia site is presented in Figure 5.

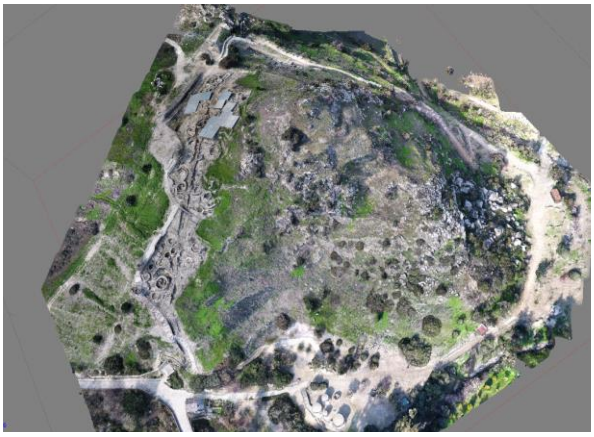


Figure 5. 3D model of Choirokoitia site

The GNSS control network established in the site included 4 GPs sites which measured displacement east (DE), Displacement North (DN) and Displacement Up (DU). The coordinates used are based on the Cyprus Local Transverse Mercator projection system (LTM) which is based on the Datum Cyprus Geodetic Reference System of 1993 (CGRS93) that uses the ellipsoid WGS84. The results of the GNSS control network found a change of 2cm during the 24 months of the monitoring period of the site.

A PSI analysis was conducted of the Choirokoitia general area to determine any micro-movements in the area, using 26 Cosmos Skymed SAR images from the years 2011-2017. For the dates defined, the points exhibit an average of 3.3 cm rate of movement per year. The results of the PSI analysis found displacement at the same area as the GNSS control network.

5. Conclusions

PROTHEGO's case study of Choirokoitia, Cyprus provides an example of how to detect and analyze deformation phenomena for monitoring and predicting geo-hazards using InSAR ground motion data and field survey techniques to measure and document the extent of damage of the natural hazard on the cultural heritage site. The InSAR data, GNSS, total station and level were used to measure the micro-movements, while the UAV and photogrammetry are used for documentation purposes and 3D modeling comparison. The PSI analysis and GNSS Control Network of the Choirokoitia site showed a small displacement. This indicates the need for longer-term monitoring of the site to diagnose the severity of the geo-hazards. The rockfall modeling indicated a potential rockfall situation near the Choirokoitia site, which may endanger visitors to the site. Local-scale monitoring data is the base for the development of geological and geotechnical modelling of the investigated sites, which will provide evolution models for the deformation processes affecting the heritage sites in order to recognize the best mitigation strategies and to evaluate the effectiveness of these actions for cultural heritage protection.

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Session 3

Cultural Heritage Databases

RECONSTRUCTING CONTEXT AND MEANING: A RELATIONAL DATABASE FOR SMALL FINDS

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Περίληψη

Το άρθρο αυτό αναλύσει κάπια πρακτικά και μεθοδολογικά προβλήματα που σχετίζονται με την ανάπτυξη μιας βάσης δεδομένων που υλοποιήθηκε, ως μέρος ενός διδακτορικού έργου που επικεντρώνεται στην ανάλυση των μικρών ευρημάτων που βρέθηκαν στις κρητικές τοποθεσίες της Φαιστού και της Αγίας Τριάδας. Η φύση αυτών των ευρημάτων και η ιστορία των ανασκαφών έχουν οδηγήσει σε μερικές επιλογές μεθόδου που θα παρουσιαστούν εν συντομία. Η πρώτη πτυχή είναι αυτή της ανάλυσης των αρχαιολογικών πλαισίων που μπορεί να πραγματοποιηθεί χάρη στις ικανότητες της βάσης δεδομένων, μέσω της διαχείρισης των στρωματογραφικών και χωρικών δεδομένων (spatial data), κατάλληλα ομαλοποιημένων. Μια δεύτερη πτυχή είναι η ανακατασκευή της σημασίας και επομένως της λειτουργίας αυτών των ευρημάτων μέσα στο αρχαιολογικό πλαίσιο τους, που περιπλέκεται από την ίδια τη φύση των μικρών ευρημάτων. Στη βάση δεδομένων αυτή η πτυχή αναπτύσσεται λαμβάνοντας υπόψη τις συστάδες που αποτελούνται από ομοιογενείς κατηγορίες ευρημάτων, κατάλληλα τυποποιημένες και διαχειριζόμενες από την Fuzzy Analysis.

Abstract

This paper describes some practical and methodological aspects related to a development of a relational database. It has been realized as part of a PhD project focused on the analysis of the small finds found on the Cretan sites of Phaistos and Ayia Triada. The nature of these finds and the history of the excavations have led to some methodological choices that will be briefly presented. The first focus is on the contextual analysis that can be achieved thanks to the potentiality of the database, through the management of stratigraphic and spatial data, appropriately normalized from the terminological point of view. A second aspect is the reconstruction of the meaning, and therefore of the function of these findings in their context, which is in itself complex because of the nature of small finds. In the database this aspect is developed taking into account groupings made by homogeneous categories of finds, properly standardized and managed with the Fuzzy Analysis.

Λέξεις Κλειδιά/Keywords: Crete, Context, Function, Database management, Standardization, Fuzzy Analysis

1. Introduction

The study presented in this article constitutes part of a PhD project (Figuera 2017a) in which a relational database has been created for the management of the so-called small finds coming from the two Cretan sites of Phaistos and Ayia Triada.

This research activity is linked with a wider project related to small finds dated from the Neolithic to the end of the Bronze Age found on the two sites. The study is still in progress and involves many scholars that deal with different materials and carried on through the study of different categories of finds, in order to attain their final publication. It is therefore part of the project *Phaistos and Ayia Triada: Small finds and Contextual Analysis* funded also by the Institute of Aegean Prehistory (INSTAP), the University of Catania and the Italian Ministry of Foreign Affairs.

The choice of the realization of a purposely designed IT tool was due to the problems of interpretation and management of this complex group of artifacts. The complexity is linked with the long period of time of the excavations – the two sites have been investigated, not continuously, since 1900 up to today – and with the proper nature of this kind of artifacts, as will be shown below.

2. Case study

Phaistos and Ayia Triada are two of the most important Minoan sites in Crete, with a very long history started in the Final Neolithic and continuing across the centuries, through the Mycenaean, Greek and Roman period, until to the Medieval and Venetian period (for the history of the researches see La Rosa 2000, 2003).

The huge amount of material and sources available has imposed some choices. First of all the chronology: the project involves the material from the Minoan Phase, divided into the Prepalatial, Protopalatial and Neopalatial periods. Second the subject, which is the category of the small finds.

2a The 'small finds'

'Small finds' is in general a term used in archaeology to designate many kinds of portable artifacts, made of different materials, but usually chronologically and functionally non diagnostic (Dierckx 1992, 2-3; MacDonald 2016). This category generally excludes therefore small objects such as pottery, stone and metal vessels, and other luxurious classes of materials (like sculptures, paintings, jewellery, seals and sealings, etc.) whose formal features allows a refined chronological and functional setting.

What makes small finds difficult to study is their peculiar nature. Their name can be misleading: they are not simply objects of less relevance or small in size, but artifacts connected to a wide range of aspects of everyday life, in fact they play a primary role in many activities (e.g. domestic, liturgical, ritual, productive and craft). For a long time small finds have remained on the edge of archaeological scientific interests (Lucas 2001, 79) and their informative potential has often been underestimated (for their perception and potentiality in archaeology see Figuera 2017b). On the contrary they can shed light on a wide range of activities and practices that can also be useful for the reconstruction of cultural and social aspects (Gillis 1988; Soles, Davaras 2004; Steel 2013, 190).

The project involves a well defined group of artifacts, especially linked to artisanal sphere and everyday life aspects. In particular it includes (1) metal objects such as weapons, tools, toilet implements, etc.; (2) stone objects like tools, lamps, mortars, pendants, stone moulds, etc.; (3) clay objects such as some special containers, house models, clay tubes, moulds, lamps, fire-boxes, cooking pots, etc.; (4) bone objects especially little tools, toilet implements, pendants, etc.; (5) and others objects made of ivory, rock crystal, etc.

2b The contextual approach

The contextual approach is the main tool for understanding small finds. Their potentiality is strictly linked with their original context, since their meaning can only be properly understood in their association to other related artifacts and spatial locations.

This approach, based on a strong tradition of research, is aimed at the reconstruction of the contextual associations. In other words the purpose must be directed towards the identification of a network of relationships that exists between objects or between artifacts and layers, an usual method, but which takes on great importance for the own nature of this kind of finds. It is useful in order to highlight those cases where similar objects can perform different functions: small finds, in fact, can be multifunctional objects (Figuera 2017b).

3. The database

In order to make the most of the knowledge potential of small finds, the project was focused on the creation of a relational database. The database is structured in 26 tables able to manage a very wide range of data about the sites and the finds (Figuera 2017a; 2018). The database development started from the realization of the conceptual model (the main concepts and the main relationships among the informational needs), across the logic model (the first structural definition regardless of the hardware or software that will be used) until to the creation of the physical model (the defined structure).

The database currently collects all the information about 1222 small finds from Phaistos and 644 from Ayia Triada. The information related to each find are: the area and date of discovery, the stratigraphic position, the inventory numbers, the typology, the size and the material description, the chronology, all the reference sources (published and unpublished data, inventory sheets, excavation diaries, etc.), the graphical documentation, and finally the functional attributions with the belonging to the Fuzzy levels and to the ICCD classification (*Istituto Centrale per il Catalogo e la Documentazione*, the Italian Institute that is responsible for cataloguing and documentation standards) (Fig. 1).

4. Methodological problems

The main methodological problem was identified during the collection of all the data, many of them linked to the old excavations. In fact Phaistos and Ayia Triada have been excavated since the start of the last century and the archaeological investigations are still continuing. Terminology is not standardized and much information is not homogeneous and too generic, making data reconstruction hard.

To permit a correct analysis it was necessary to bypass this problem. A terminological normalization has been done, to avoid the abundance and the disaggregation of the sources and the absence of a scientific and unique dictionary. This operation affected the indications about the discovery areas and the stratigraphy.

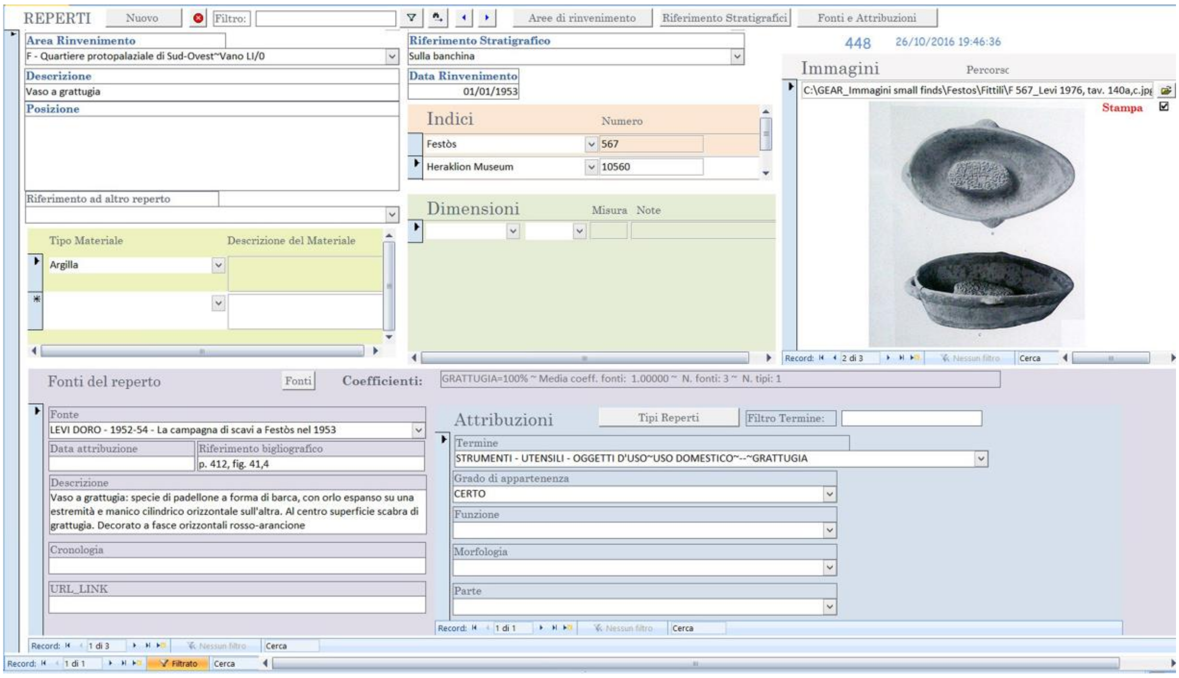

Figure 1 Form 'Finds': with all the information about the small find ID 448 (Figuera 2017a).

The information related to the context is managed in the tables 'Discovery Areas' and 'Stratigraphic References'. In both cases there are different levels of detail linked by a recursive relationship. In the first one the spatial location is managed from a wider level (e.g. the quarters) to a more defined level (e.g. the rooms). In the second one the stratigraphic references are managed from generic terminology (e.g. 'floor plan') to the single stratigraphic unit. The stratigraphy is also defined by another attribute – context typology – that makes a distinction between primary contexts and secondary contexts.

5. Contextual analysis

The contextual analysis in the database is possible according to different search keys and multiple associations, through several queries and specific database functions.

The information may be extracted with simple correlation between different tables or inside the same table (e.g. simple join between 'Finds' and 'Stratigraphic References'). Another query is the so-called pivot which allows the crosstabulation analysis, useful for example to obtain the number of finds found in a macro area, crossing the information about the discovery area and the stratigraphic data (Fig. 2).

So it is possible to highlight: the relationships between the finds and the stratigraphic and spatial data; the repetition of contextual associations; the 'weight' (meaning the quantitative aspect) of the finds inside deposits.

AREA_RINVENIMENTO_ESTESA	Totale di ID_REPERTO	Non specificato	Armadio a muro	Riempimento	Riempimento sotto il piano pavimentale del Primo Palazzo	Riempimento sotto la gettata di calcestruzzo	Riempimento sotto la gettata di calcestruzzo~Aderente allo strato di calcestruzzo	Sul piano pavimentale	Sul piano pavimentale~Riempimento	Sulla banchina	Superficiale
F - Quartiere protopalaziale di Nord-Ovest	1	1									
~Corridoio III/7	1				1						
~Vano IX (Sacello)	4	1						1		2	
~Vano V (Sacello)	3	1						2			
~Vano VI (Sacello)	3			1				1		1	
~Vano VII (Sacello)	5	3						2			
~Vano VIII (Sacello)	15		2	1			7	5			
~Fossa a Nord del Sacello	10	1						9			
~Vano X	10		6	2		1		1			
~Vano XI	1			1							
~Vano XII	2								2		
~Vano XIII	1			1							
~Vano XX	2		1					1			
~Vano XXI	2									2	
~Vano XXXIV	1										1

Figure 2 Pivot table between 'Discovery areas' and 'Stratigraphic references' (Figuera 2017a).

6. Functional analysis

Another aspect is related to the possibility to propose the reconstruction of the function, and consequently of the meaning, of the small finds analyzed in their context.

In general the functions of the small finds are not so simply to understand because of their variety: they may be employed in the private sphere (e.g. domestic activities) and in the public sphere (e.g. liturgical and ritual activities and in many different kinds of industrial activities, such as metallurgy, stone working, pottery production, etc.). As already mentioned, in fact, they may be multifunctional objects: the same typology of find may have different functional features, and may be used in different activities.

For example in a Neopalatial context in Phaistos were found a group of double-axes that because of their shape can be classified as tools, but they may have a cultic function because they were founded in a lustral basin, they are in association with ritual objects and finally they have no wear traces. So this means that these objects, usually used as tools in craft works, in this case had a cultic function (see Baldacci 2008).

6a Standardization

In order to normalize the terminology of the typologies and the functions has been chosen the Italian national standard ICCD.

This vocabulary is organized in different hierarchical levels, the first three are pertinent to the 'CLS (classes and production) category' and the last two pertinent to the 'OGTD category' (one level for the definition, and the second one for others details such as the morphology, etc.) (MiBACT 2014a, 2014b). In the database this organization is made in the 'Level Type Finds' table and allows the first functional definition. In particular the CLS category is fundamental for the functional analysis.
During the data entry the database, after filtering for typology, permit to select from a list of 'CLS category' terms, since the same type may have different functions (e.g. the type 'needle' is classified in the first level with the term 'Instruments-Tools-Use objects' and in the second level could have four different functional categories: 'Hunting-Fishing', 'Medicine', 'Weaving-Needlecraft', 'Hygiene-Toilet'). In this way the find in the database is not simply classified according to its typology, but its function is also defined. This makes it possible to work with homogeneous 'functional groups', allowing quantitative analyses and comparison between different discovery contexts.

6b Fuzzy Method

To manage all these information the database has been developed with a specific attention to the functional attribution made by the referred sources. It was considered that a single find may be subject to different attributions by different scholars, or by the same scholar at different times.

So, in the database there is a table, called 'Finds Sources' (in which all the sources for each find are listed), as an intermediate store between the tables 'Finds' and 'Finds Attributions' (in which there are all the typological attributions for each scholar) to connect multiple attributions to the artifact and its source (Fig. 3). Thanks to all the data in these tables it is possible to underline the plurality of the typological attributions for the same artifact.

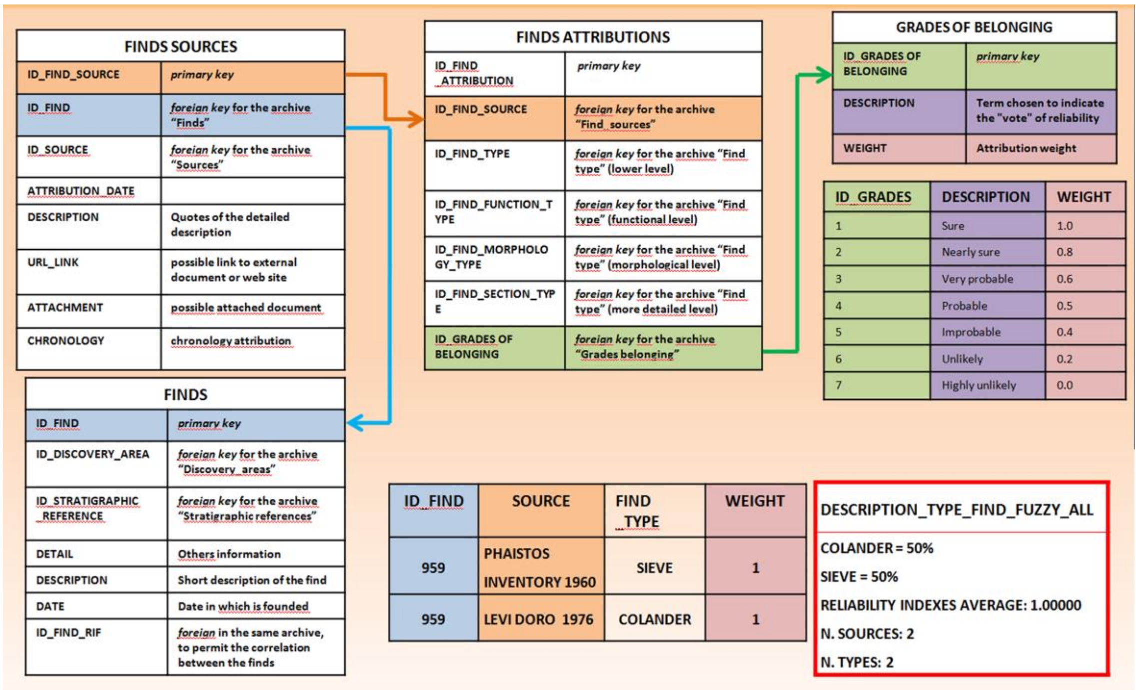

Figure 3 Links between the tables 'Finds', 'Finds Sources', 'Finds Attributions', 'Grades of Belonging' and an example of application of Fuzzy Method.

In the end the database has been implemented to process the concept of 'probability of belonging' of an object to a specific typology or class, through those tables which allow multiple typological assignments. This is possible thanks to the Fuzzy Method applied in the table 'Finds Attributions': for every record set, an 'attribution weight' is managed by the table 'Grades of Belonging' with the assignment of a decimal number (between 0 and 1) (Figuera 2016, 2017b). Every number corresponds to a different term: 1.0 = sure; 0.8 = nearly sure; 0.6 = very probable; 0.5 = probable; 0.4 = improbable; 0.2 = unlikely; 0.0 = highly unlikely (for the many applications of Fuzzy Logic in archeology see Crescioli, D'Andrea, Niccolucci 2000, 2002; Niccolucci, D'Andrea, Crescioli 2001; Hermon, Niccolucci 2002, 2003a, 2003b, 2017; Hatzinikolaou *et al*. 2003; Hermon *et al*. 2004; Baxter 2009; Jaroslaw, Hildebrandt-Radke 2009; Farinetti, Hermon, Niccolucci 2010).

The application of this method is made in order to determine for each item 'how much' it belongs to a specific typology or class. In some cases this method underlines a high reliability index, but suggests a detailed study in order to clarify the typology attribution. When the reliability index is too low it might be appropriate to exclude the object from the contextual analysis.

7. Conclusions

The creation of this tool optimizes the informative value of the small finds. Through its functions is possible to create specific analyses aimed to underline (1) their widespread presence in different types of archaeological contexts, (2) their functional and technological aspects, (3) their link with different everyday activities and (4) their multi-functionality. The purpose of the reconstruction of small finds contexts and meanings was achieved through the methodological choices of the use of standard terminology and the application of a mathematical method able to manage the level of certainty. Thanks to this possibility of reinterpreting data it is possible to examine the findings with a free interpretative process. These methodological approaches may be a suitable solution for the management of other kinds of artifacts too.

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SIMPLEX ARCHAEOLOGICAL INFORMATION MANAGEMENT SYSTEM: AN INTRODUCTION TO SYSTEM COMPONENTS AND FUNCTIONS

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Περίληψη

Η ακριβής και εις βάθος καταγραφή αρχαίας κεραμικής θεωρείται ως μία από τις πιο πολύπλοκες εργασίες στην αρχαιολογία κυρίως ένεκα της πολυθετικής φύσης της κεραμικής, αλλά και των πολύπλοκων σχέσεων μεταξύ των χαρακτηριστικών της. Το σύστημα διαχείρισης αρχαιολογικών πληροφοριών με το όνομα SimpleX έχει αναπτυχθεί πρόσφατα με στόχο την εννοιολογική συστηματοποίηση της μεθοδολογίας καταγραφής κεραμικής, τη μείωση του χρόνου και της ενέργειας που απαιτείται για την καταγραφή κεραμικής στο πεδίο, αλλά και τη διευκόλυνση μετατροπής των δεδομένων σε διαλειτουργικά Συνδεδεμένα Δεδομένα. Το σύστημα SimpleX αποτελείται από μία οντολογία που επεκτείνει υπάρχοντα εννοιολογικά μοντέλα αναφορά, μια βάση δεδομένων και προσαρμοσμένο γραφικό περιβάλλον χρήστη που επιτρέπει την εισαγωγή, διαχείριση, διερεύνηση και εξαγωγή δεδομένων. Το παρόν άρθρο στοχεύει στην παρουσίαση των συνιστώντων μερών του συστήματος και στην εισαγωγή του αναγνώστη στις κύριες λειτουργίες του.

Abstract

Documenting accurately and in-depth archaeological pottery is considered as one of the most complex tasks in archaeology owing to the inherently polythetic nature of pottery and the overlapping relationships between its attributes. The SimpleX archaeological information management system has been recently developed with the aim of conceptually systematizing the recording methodology, reducing both time and effort required to document archaeological pottery in the field, and facilitating the transformation of data into interoperable Linked Data. The SimpleX system comprises an ontology that extends existing conceptual reference models, a database and a customized graphical user interface that allows data input, management, querying and output. The present paper aims to briefly present each component of the system and introduce the reader to its main functions.

Λέξεις Κλειδιά/Keywords: Cultural heritage, natural hazards, remote sensing, UAV, geodetic techniques, JPI

1. Introduction

The point of departure for the present paper is not to be found in Digital Cultural Heritage, as the title may suggest, but in literature and more specifically one of the first adventures of Sherlock Holmes entitled “A Scandal in Bohemia”, where the famous detective replies to a hypothetical question by his long-time companion Dr. Watson with the following assertion: “It is a capital mistake to theorize before one has data. Insensibly one begins to twist facts to suit theories, instead of theories to suit facts.” (Conan Doyle 1892: 7). This maxim eloquently and unwittingly summarizes a major issue for the philosophy of archaeology, namely that for archaeological, and indeed scientific, theories to attain any degree of truthfulness, it is necessary to first capture alethically neutral data and afterwards convert them to formal knowledge (Bunge 2003, Cocchiarella 2007, Primiero 2008). Relevant to the former part of this issue, the SimpleX project was initiated in 2016 with the specific aim of establishing an effective way to logically structure and capture data for use and reuse by archaeologists in Cyprus. More specifically, the project focuses on archaeological ceramics, a type of material that is considered difficult to record due to its inherently polythetic nature and the complex relationships existing between its properties (see Barlow *et al.* 1991, 5-7, Baird 1991). Added to the above, since the 1990s the archaeology of Cyprus has been consistently growing, and the multitude of research activities on the island, such as excavations, surveys and laboratory analysis projects, has led to the production of several digital archaeological datasets, which unfortunately remain inaccessible to research due to a stark lack of centralized policies regarding digital cultural data management; the nonapplication of international recording protocols, and the use of diverse and often incompatible data recording systems. These conditions necessitated the development of the SimpleX ontology and system, which set as its principal objectives the establishment of a standardized model of information recording for archaeological ceramics that adopts internationally recognized conceptual reference models and the compilation of an integrated relational management system for digital archaeological information capable of transforming the collected information into exchangeable Open Linked Data. The SimpleX ontology and recording system are meant to provide a template for projects working on archaeological ceramics in Cyprus and each component of the system and their main functions are briefly presented in this paper.

2. SimpleX Ontology

Prior to designing and compiling an archaeological information management system and after consulting relevant literature (D'Andrea *et al.* 2006, Cripps and May 2010, Huggett 2012, Bertoldi *et al.* 2015, May *et al.* 2015, Biagetti 2016), it was deemed appropriate to establish *ab initio* its ontological structure expressed in the form of a conceptual reference model (henceforth CRM), as the latter would enable a deeper understanding of the definitions and relationships between information objects and prevent data degradation in the long run (Cerf 2011). In order to accomplish the task, two current complementary CRMs were adopted based on their suitability for the purposes of the project and their extensibility. The first is the CIDOC-CRM (Le Boeuf *et al.* 2015, see also Doerr *et al.* 2016), which is an internationally recognised ISO standard for the exchange of cultural heritage information and the documentation of archaeological objects; while the second is the CRM-EH (May 2014), an extension of the afore developed within the activities of the STAR and DELOS projects in support of the Centre for Archaeology's Revelation project to model the archaeological processes of excavation and artefact analysis (Binding *et al.* 2010, Tudhope *et al.* 2011, May *et al.* 2011). The two ontologies were initially assembled in the Protégé ontology editor (Musen *et al.* 2015) to lay the groundwork for an ontology representing the analysis of archaeological ceramics, which is a domain not explicitly considered or encompassed by the aforementioned ontologies.

Thus, the second stage of ontological modelling commenced with the aim of extending the CIDOC-CRM and CRM-EH ontologies to include entities, properties and relationships reflecting the processes of macroscopic, microscopic and laboratory analysis of archaeological ceramics. At this point, it should be noted that the fundamental noetic construct ceramic is considered here to be a physical spatiotemporally existing subclass of the E22 man-made object class under the E92 spacetime volumes and E77 persistent items superclasses in accord to CIDOC-CRM and is itself a superclass of etically defined sub-entities. These include the concepts of fabric, surface and shape, which are thought to represent different inter-related aspects of the pottery making process that variously inform the archaeologist of the past. At first, the fabric is considered to represent the technological knowledge and experience involved in the production of pottery, and provides information relevant to the technology and technique of manufacture, while it can also indicate the spatial extent of technology adoption and the passage of time when changes attributable to technological, and particularly pyrotechnological changes are observed (Rice 1987, Ch. 2-5, Orton & Hughes 2013, Ch. 5, 10, 13). Secondly, the surface, although entailing some technological choices and application of technical skills and knowledge, is perceived as the playing field of style and is considered to express cultural and social choices regarding the visual presentation of pottery, hence it can potentially provide indications regarding the stylistic choices, spatial extent of decorative styles adoption and often the expression of identity by population groups, communities and/or individuals producing or consuming pottery (Rice 1987, Ch. 5, 8, Orton & Hughes 2013, 86-92, 133-134). Finally, shape and related metric attributes are considered to be the result of functionalist and to a lesser extent behavioural choices regarding the intended vessel form, function and use, thus they provide information on various functional-behavioural aspects of the pottery producing and consuming communities and aid the exploration of themes like subsistence, storage, ritual and trade among others (Rice 1987, Ch. 7, Orton & Hughes 2013, Ch. 6, 12, 14). These three main sub-entities - fabric, surface, shape - were subsequently deconstructed to a complex network of related entities reflecting their ontic and epistemic multi-valued and often fully or quasi-polythetic quantitative and qualitative properties. Next, the newly defined entities of the ontological model were mapped in Protégé to form the SimpleX ontology and were associated via extant properties with several entities in the CIDOC-CRM and CRM-EH models, and specifically with entities within the E4 Period, E28 Conceptual Objects and E55 Type superclasses. It is further noted that SimpleX, being a narrow and special purpose ontology, heavily utilizes Data Properties to associate certain sub-entities with specific primitive datatypes built-in Protégé, such as string, decimal, float, date, and others, which abide by the W3C Recommendations regarding the XML Schema Datatypes (Peterson *et al.* 2012).

In the final stage of ontological modelling, all SimpleX entities were re-evaluated and any entities with definitions that were deemed to be conceptually overlapping with existing entities in CIDOC-CRM and CRM-EH were either clarified or removed, so as to avoid unnecessary obfuscation of the ontology and replication of entities. After clarifying the overlaps, the HermiT reasoner was utilized to track orphan entities, identify subsumption relationships between classes, and ensure overall ontological consistency. Finally, the SimpleX ontology upon full annotation was exported in the RDF/XML syntax.

3. SimpleX Database and User Interface

Following the finalization of the SimpleX ontology, the project moved to its second phase that entailed the compilation of a database and a graphical user interface, so as to test the potential of the CRM as a guide for structuring a database schema intended for practical use in the field (Cripps & May 2010). Since SimpleX was undertaken as part of the broader activities of the Settled and Sacred Landscapes of Cyprus (SeSaLaC) survey project, the first step toward construction of the archaeological information management system was to consult with the director of SeSaLaC, Dr. Athanasios Vionis, so as to adapt the system structure and design to the particular needs of the survey project without altering the underlying ontology. These requisites included the storage of data locally and the function of the system in the absence of a network connection, the execution of standard Create-Read-Update-Delete (CRUD) actions and SQL queries, so as to record, manage, alter, search and interrogate the data stored preferably through a customizable Graphical User Interface (GUI); the storage of textual, numerical and array data and linking to attached research and audio-visual data, such as photographs, video, animations, sound clips, 3D models, CAD files, spreadsheets, raw data files from specialised software and any other digital files with extraction of their metadata from shell properties handlers in Windows operating systems; the separation of the back-end database from the front-end GUI, the strong encryption of all data stored in the database and the secure accessing of the system by various categories of users requiring a permissions management system; the support for the Open Database Connectivity (ODBC) interface in order to transfer or link data to third-party software packages for statistical and spatial analyses; the export of information in XML in accord with the SimpleX ontology to avoid data degradation (White *et al.* 2009, Cerf 2011); and finally the compilation of a GUI that acts both as a data management and student learning facility, since the system is intended to function as a knowledge hub for Cypriot pottery.

After the initial consultation, a broad literature review was undertaken to explore the available technologies for project implementation, decide the approach to system design, and harvest ideas on the front-end interface functionalities and appearance. Several online and offline archaeological software programmes were examined, and even though in many cases the database structure in the form of a schema exhibiting data fields and their relationships was not accessible or was not made available, the GUIs were systematically analysed to approximate the schemas structure. The cases analysed included both databases from projects in Cyprus, such as CADiP (Pilides 2012), STARC-Repo (Ronzino *et al.* 2012), CARMA (Paraskeva 2016), Marki-Alonia and Politiko-Kokkinorotsos excavation projects databases (Frankel & Webb 2006, Webb *et al.* 2009), and the TAESP surface survey database (Given *et al.* 2007); but mostly archaeological information management systems from projects outside the island, such as REDATO (Ozawa 1992), IADB (Rains 1995), IDEA (Andresen & Madsen 1996), POLEMON (Bekiari *et al.* 1999), 3D MURALE (Cosmas *et al.* 2001) Stratify (Herzog 2004), ABMAP (Serjeantson 2005) Arachne (Dally & Förtsch 2007, Förtsch & Keuler 2011), Open Archaeology Software Suite (Puttick 2007), SHARD (Praetzellis *et al.* 2008), ARK (Eve & Hunt 2008), CISAR (Henze *et al.* 2008), SWISHOASIS (McKeague & Jones 2008), IReMaS (De Felice *et al.* 2009), PARP: PS (Wallrodt 2011), Easy Recording System (Bobowksi 2012), Odyssée (Bourrouilh 2012), ARCHEOSEMA (Ramazzotti 2013), PIQD (Smith *et al.* 2014), THESAURUS (La Monica *et al.* 2014), ARCHEOFI (Andreozzi *et al.* 2016), SITAVR (Basso *et al.* 2016), and ArchAIDE (Dellepiane *et al.* 2017). The in-depth exploration of the aforementioned use cases led to the adoption of a functionalist-presentational approach to database and GUI compilation (Schlader 2002, 519), the selection of a database software package with object-based programming capabilities that allows offline use and local storage of the input data, and the development of the system based on the mandates of the Rational Unified Process (Shuja & Krebs 2008, Kruchten 2009).

On the basis of requisites and available technologies, the software package selected for the compilation of the database and GUI for the SimpleX system was Microsoft Access 2016. The particular software was selected because it combines the relational Microsoft Jet Database Engine 16 with graphical user interface and application development tools. The database engine can handle relational databases, run CRUD actions, index fields with data in ASCII and Unicode character encoding, provide security by splitting the database and encrypting the back-end data, ensure referential and entity integrity for data normalization purposes, lock pages and records for multi-user use scenarios, and run most types of Structured Query Language (SQL) queries defined in Microsoft Query By Example (QBE); while the development tools can be used to create the GUI and enhance its functions with advanced automation, error trapping, data validation, and multi-user support via Office macros and custom code compiled in the underlying Visual Basic for Applications (VBA) that also supports Data Access Objects (DAO), ActiveX Data Objects (ADO), Object Linking and Embedding Database (OLEDB) and ODBC for developing native C/C++ programs.

Selection of the system development software was followed by the construction of the database and the GUI. The database schema replicates the structure of the SimpleX ontology with extra fields necessitated by technological requirements, comprises 31 tables

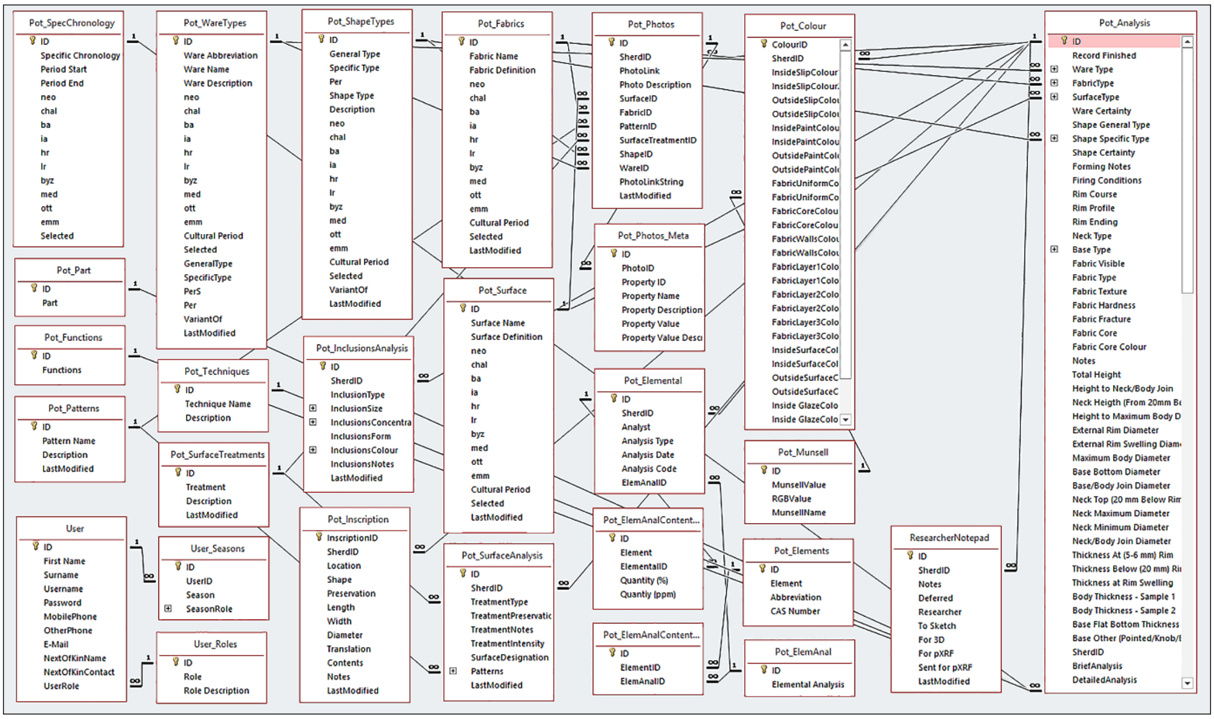

Figure 1: Database schema for the SimpleX system showcasing the tables and their relationships.

most of which inter-related, and maintains the rules of the third normal form of database normalization (3NF, Kent 1983, 121) both by decomposing the initial tables into primary and dependent tables in order to reduce data redundancy/duplication and by observing strict referential integrity rules between table relationships to improve data integrity (Fig. 1).

During the design of the database, one of the principal issues in pottery recording regarding data multiplicity and uncertainty was also tackled, first by identifying the instances when multiple and/or uncertain information could potentially be needed, such as in the cases of shape, ware, fabric, surface and dating classification, as well as in the recognition of colours, surface treatments, decorative motifs and fabric inclusions; and second by allowing the input of such multiple data either in one-to-many related tables or in MS Access many-valued fields (MVF) with the uncertainty of such information being stated in separate tick-box or list fields alongside the multiple data. Another major concern during the compilation of the database regarded the storage of digital files of the SimpleX project alongside their related data in the database. Although it is possible to embed digital files within the database as OLE objects or attachments, due to the internal size limit for any table holding such items to just 2GB, the expectation of a large number of photos (currently c.3600 photos taking up c.21GB), and the need to record metadata for the digital objects related to input data, it was decided to opt for object linking by referencing relative paths to any digital object placed in a predefined folder stored in the same folder as the back-end, which translates to the ability of migrating the database and the related digital objects without losing the links between them. Other issues resolved during database construction regarded data security and system performance. In order to protect the collected data, improve the speed of queries, and be able to modify the GUI without the need to maintain access to the collected data, the database was split in two sections, namely the back-end containing the data in tables, and the front-end that stores the GUI and queries. All the back-end data and the VBA interface of both the back-end and GUI were password encrypted utilising the CryptoAPI Next Generation (CNG) Advanced Encryption Standard 256-bit (AES-256) algorithm with the passwords masked using the 160-bit Secure Hash Algorithm 1 (SHA-1).

Turning to the GUI, it consists of 38 forms, of which 11 main forms and 27 auxiliary forms and subforms nested within the main forms; 39 select, append or update queries comprising 79 SQL statements and expressions, 6 modules and 4 class modules together consisting of 1715 lines of VBA and machine code. Even though the MS Access native tools were utilised to construct most aspects of the GUI, its design, functionalities, performance and features were further augmented and expanded by employing several macros, and 5986 lines of VBA, DAO and ADO code.

However, as stated in the introduction, the SimpleX system was not designed to simply allow data input, but set out to resolve several issues that concern the documentation of pottery, and more explicitly the accuracy, reliability, speed and efficacy of their recording. Customarily, due to the complexities of documenting pottery and the numerous attributes associated with them, several projects and databases do not attempt to enforce rigid structures in the recording system, and instead allow the input of free text in most GUI fields (see for example Pilides 2012; Berlin 2016). The practice of manual input of textual information, though flexible, is very time consuming, whilst it is also the main source for the introduction of errors into a database due to the inclusion of wrong data types, input of data in the wrong fields, typos, inconsistent use of pottery terminology, unnecessary duplication of data, and input of non-usable data for further analysis purposes. To offset such phenomena, a different approach was adopted in SimpleX. Instead of free

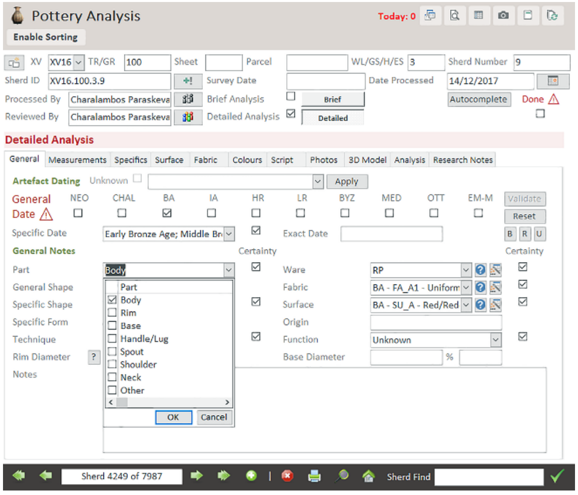

Figure 2. The main GUI of the SimpleX pottery recording system showcasing the main form for data entry.

text, the user is allowed to utilise a range of prepopulated expandable single- and multiple-choice lists, tick-boxes, and fields accepting specific forms of data, such as numbers, dates, data arrays and texts in predefined forms, while the input of free text is only allowed in fields that store comments, notes and other non-essential observations regarding the pottery being described (Fig. 2). Preliminary testing of this input method during the 2017 and 2018 field seasons of the SeSaLaC project indicates an increase in the speed of recording pottery and a drastic reduction of errors even by non-specialist, supervised users of the system (Thanasis Vionis, Pers. Comm.).

One of the drawbacks of the abovementioned method of data input is that it requires on the one hand the compilation of thesauri carrying all the necessary archaeological terms, and on the other hand a process to narrow down the terms populating specific drop-down lists. The former issue was tackled by populating lists carrying technical terms using native MS Access mechanisms and by creating a number of subforms that act as thesauri for certain important fields, such as wares, shapes, fabrics, surface types, and surface

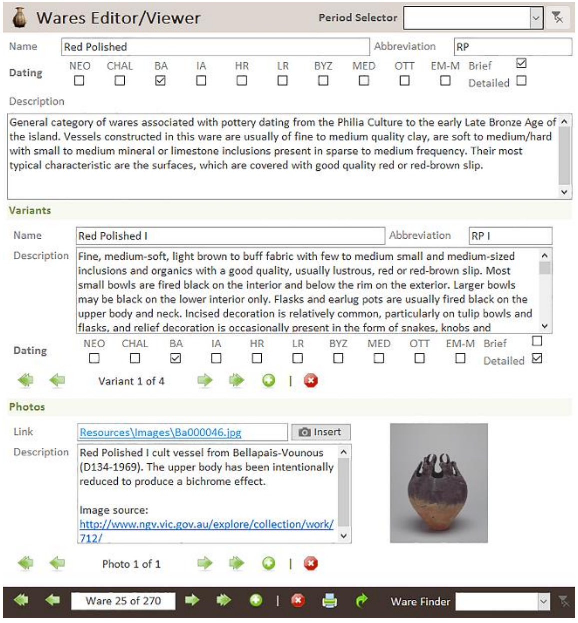

Figure 3. The Wares Editor/Viewer in the SimpleX system, one of the thesauri that functions as a knowledge hub for Cypriot ceramics.

treatments of Cypriot ceramics,. These subforms can be edited only by administrators and expert pottery analysts, so as to better control the data on the terms included in each thesaurus, verify the veracity and accuracy of the data, and expand the terminology as required by novel finds and the call for multivocality in archaeological documentation efforts (see Hodder 2008, Richardson 2014). Beyond cataloguing terms, however, the subforms are accompanied by several other fields, such as dating, textual descriptions of the terms, photos and relevant bibliography. Essentially, this sub-system of thesauri functions as a knowledge hub for Cypriot pottery from the Ceramic Neolithic to the Early Modern period and is accessible by all the users of the system (Fig. 3).

Having established the thesauri, the second issue of data presentation became apparent, as the inclusion of hundreds of terms from the thesauri into prepopulated lists rendered their use very difficult for the end user. This issue was tackled by developing two separate processes: one for terms bound by temporal periods, and one for terms not bound by time, like the chemical elements and compounds. In the former case, the user inputs a broad dating and then a process combining VBA code and SQL queries filters the thesauri data for the prepopulated lists, so as to include only terms that concern the selected temporal periods (Fig. 4a).

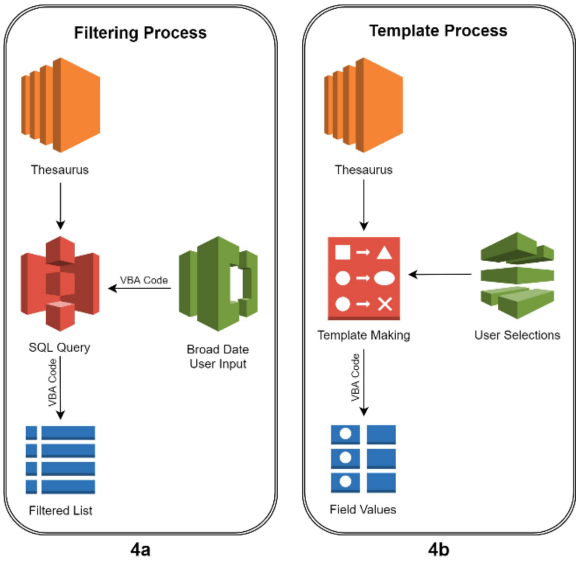

Figure 4. Diagram of the filtering (4a) and template creation (4b) processes for thesauri data use in SimpleX.

For the latter case, a second process allows for the creation of templates that store arrays of data that can then be selected from a list and via VBA the content of each template is transferred as field values to the ceramic artefact under analysis (Fig. 4b). Embedding these two processes allowed the reduction of items in prepopulated lists and consequently the more effective input of data.

Beyond the novel text-free data input method, the GUI also incorporates a range of other improvements that allow faster and more efficient recording of pottery. Speed improving features include a range of buttons and lists with VBA and DAO code behind them that allow the automatic inclusion of dates and user names, the duplication of mostly contextual information from one ceramic artefact to the next, since artefacts from the same context are often analysed successively; and the use of artefact templates that automatically assign values to most main fields like ware, shape, function and fabric. The latter templates have been prepared based on the statistical processing of data recorded during the 2015 and 2016 SeSaLaC field seasons, which highlighted the most important attributes of ceramics types from each cultural horizon. One more feature speeding up the process of pottery recording regards the often neglected collection of metadata for all the digital objects linked to the database. In this case, machine code that replicates the function of a shell property handler DLL by creating native-code x86 COM objects in memory, ActiveX, and VBA code were utilised to automatically create a thumbnail preview of the object being linked and at the same time pull all its metadata and transcribe them in an appropriately formatted table, which currently holds a little over 200 thousand rows of metadata (Fig. 5).

Moving to advances in the efficiency of documenting pottery, it is noted that the principal concerns were the provision of a user-friendly environment and the prevention of erroneous data input due to limited technological competency of the system user. These aspects of system design are particularly delicate, as the erroneous use of a system should not cause user frustration, nor lead to loss of data, introduction of non-expected data types, or inclusion of data that violate referential integrity. Beginning with the GUI design, its navigation was optimised so as to allow the end user find any piece of information sought in three to eight clicks distance from the main interface (Porter 2003, Nielsen & Loranger 2006, 322, Jiménez Iglesias *et al.* 2018, 603, contra Zeldman 2001, 448); all forms return to the last edited artefact upon loading, instead of the first artefact per the default navigation option in MS Access, while all fields in the data input forms are clearly labelled and when the cursor is on top of any field or its label, a bubble tip appears with instructions on how to input data to the field at hand. Moreover, five search and filtering mechanisms/subforms have been developed and embedded in the SimpleX system to facilitate data discovery based on identification criteria (i.e. context, id), attributes (i.e. dating, ware, shape, fabric, surface), or researcher pending tasks (i.e. detailed analysis, digital objects description, drawing, archaeometric analyses, etc.).

Returning to the issue of user induced errors, a host of error trapping mechanisms utilising VBA message boxes have been added to the GUI. These prevent the introduction of ceramic artefacts lacking contextual information, eliminate duplicate entries at the artefact level, preclude retention of period-specific data upon change of the broad artefact dating, bar non-expert users from editing, adding or deleting data in the thesauri, lock all artefact data upon completion of the analysis per the expert opinion of expert users and/or system administrators, and timestamp the last changes to any artefact. Beyond these error traps, the non-expert system user is further assisted in documenting specific pottery attributes by additional modal forms that visualize the concepts/terms included in the more technically-oriented prepopulated lists (Fig. 6), and by a mechanism that translates Munsell colours to the sRGB colour space used by computer screens to validate their colour selections regarding various pottery attributes.

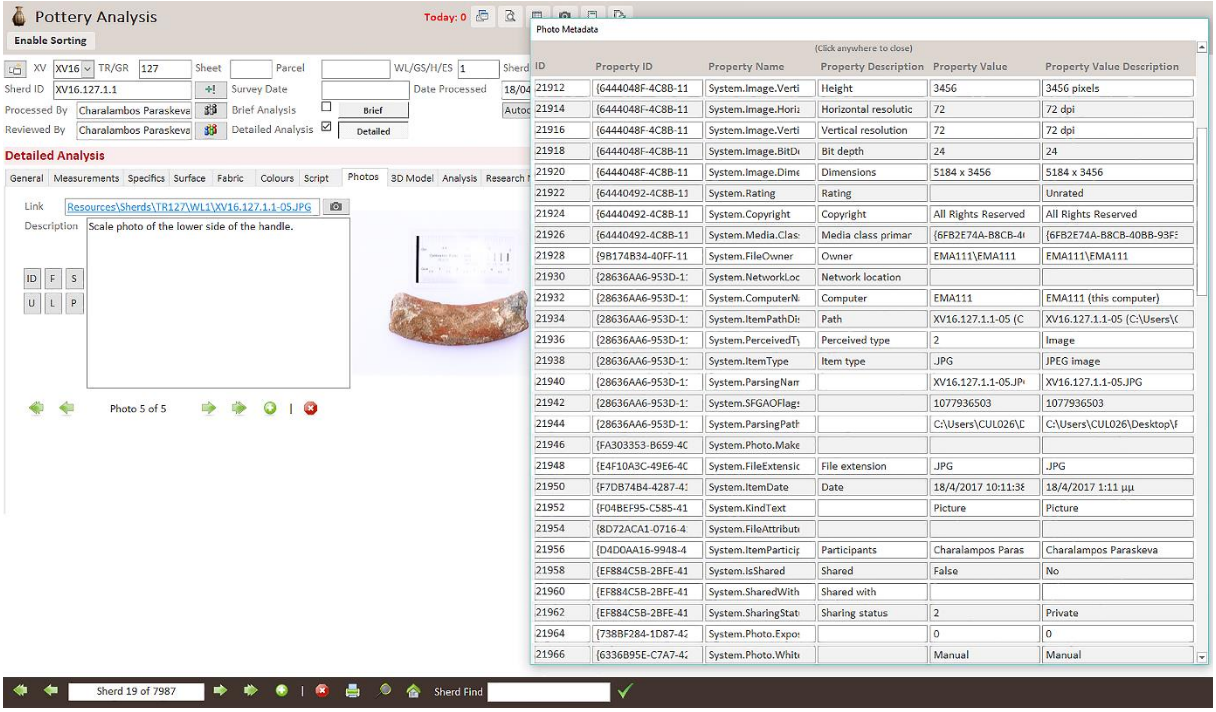

Figure 5. Attachment of a digital object to SimpleX to illustrate thumbnail generation and metadata transcription.

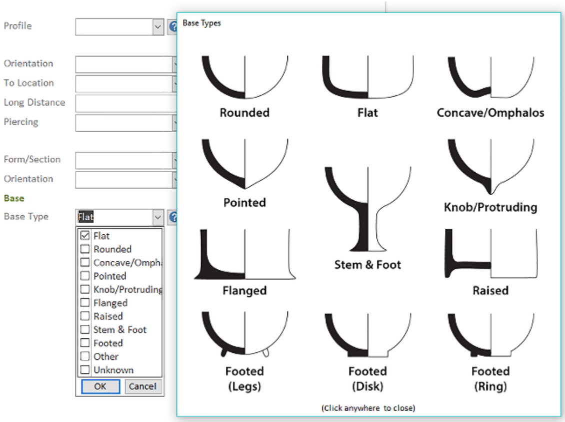

Figure 6. Close-up of a list with predefined terms for pottery bases and a modal form visualizing the terms of the list.

One final concern for the SimpleX front-end regarded data security and database safety. As MS Access is not a fully secure database, it was decided to lock down the front-end to safeguard the system from malicious users and data theft. The measures enforced include the construction of a user permissions system that manages the roles and level of access to specific system functions for various categories of users (Tbl. 1), the distribution of a compiled version of the GUI by converting it to an execute-only file (ACCDE), so as to disallow opening forms, queries and reports in Design mode; and the controlled access of users to the GUI via a secure modal, brute-force immune Login form with passwords encrypted using the CryptoAPI Next Generation (CNG) Secure Hash Algorithm 2 512-bit (SHA-512), and then masked using the 160-bit Secure Hash Algorithm 1 (SHA-1). Beyond these, the navigation pane of MS Access, all linked back-end tables, and all ribbon and file tab commands, buttons and options are hidden for most users, except pottery experts and administrators (Fig. 7); the MS Access Special Keys, all options in the right-click menus and the Shift bypass are disabled using VBA code and an AutoKeys macro, while an AutoExec macro calls the start-up procedure, which checks whether the GUI is a compiled copy, resets all of its security properties, and loads the Login form. Lastly, the entire SimpleX folder containing the back-end, front-end and the subfolders carrying linked digital objects is locked down using an advanced traverse permission, which allows users to access the front-end, but not any of the other items in the folder, which are the responsibility of expert system users and project administrators.

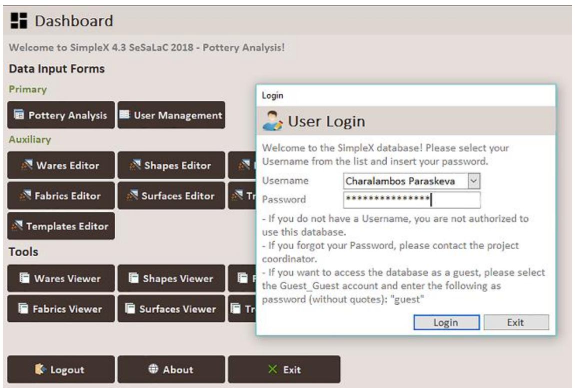

Figure 7. The Login form and dashboard first screen of the SimpleX GUI.

User access level	Permissions
Data view	Access only to GUI data areas, only data viewing allowed.
Data input	Access only to GUI data areas, data editing allowed, except for thesauri and other list data.
Advanced data input	Access to both GUI and back-end data areas, full data editing allowed, including thesauri and other list data, no access to user management, system design or settings, and the VBA interface.
Administrator	Full access to the database with the ability to modify all of its content and structure.

Table 1. The user access levels and permissions of the SimpleX system.

4. Discussion and future prospects

This paper presented in brief the main functions and components of the SimpleX ontology and information management system. The ontology aims to establish a standardized model for the recording of information for archaeological ceramics by implementing and expanding the CIDOC-CRM and CRM-EH reference models, while through the database and front-end GUI the system user can record, store, edit and manage pottery data in a secure, efficient, and semi-automated environment. Combining an ontology, a database and the GUI in a single system, as in the case of SimpleX, offers a range of benefits that include the possibility to use all system features in offline situations, the reduction of data storage and management costs, since it is a self-contained system with low computational requirements; the elimination of data non-comparability, when the system is used by multiple different projects; the possibility to adjust to specific project needs by altering only the front-end GUI, the reduction of human induced errors due to the elimination of free text inputs in the majority of fields, and the speeding up of data analysis afforded by the standardization of data structures and certain software features like complex queries construction and third-party software package connection via ODBC for data export or linking. Despite its benefits, however, SimpleX is still a newly constructed system, hence there are certain limitations to its functions and uses. First, the system concerns the documentation of survey pottery at the level of the single sherd, and does not currently support the processing of batches or groups of pottery fragments. Second, certain fields concerning the locational/contextual information for the artefacts documented have been modelled in the database according to the specific needs of the SeSaLaC project and may require slight modifications in order to apply to other archaeological situations. Finally, the system is still under field testing and although heavily debugged, on occasion errors may arise due to unexpected human behaviour. Looking to the future, the project is scheduled to conclude soon, as the ontology and the system will be made available online, the back-end database will be connected to ArcGIS in order to cross-correlate the collected data with the geodata accumulated by the SeSaLaC project, and, finally, an export mechanism will be compiled in VBA to allow the export of data for each artefact entered into the system in RDF/XML according to the SimpleX ontology, thus rendering all data fully interoperable Linked Data.

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Session 4

3D Reconstruction and Modelling

THE CAVE OF THE NYMPHOLEPT AT VARI – FAST CREATION OF A 3D SIMULATION MODEL OF AN IMPORTANT CULT CAVE IN ATTICA, GREECE

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Περίληψη

Το σπήλαιο Νυμφολήπτου βρίσκεται στον νότιο Υμηττό και ανήκει στην περιοχή Βάρης. Αποτελεί μοναδικό μνημείο που μετατράπηκε κατά την αρχαιότητα σε ιερό προς τιμήν των Νυμφών, του Πανός, του Απόλλωνος, ενδεχομένως και του Ερμή. Η κάθετη, βαραθρόμορφη είσοδός του, διαμορφώθηκε στην αρχαιότητα με την λάξευση βαθμίδων, που διατηρούνται σήμερα έντονα φθαρμένες. Η μετατροπή του μνημείου σε επισκέψιμο χώρο για το ευρύ κοινό θα απαιτούσε αλλοίωση της μορφής του, διότι θα συνεπαγόταν, κατ' ελάχιστον, την κάλυψη της αρχαίας κλίμακας καθόδου ή την δημιουργία καινούργιας, δίπλα στην υπάρχουσα αρχαία.

Η λεπτομερής αποτύπωση του εσωτερικού του σπηλαίου καθώς και του υπερκείμενου ψηφιακού μοντέλου τοπογραφίας πραγματοποιήθηκαν με στόχο τη δυνατότητα αναπαράστασης του μνημείου σε φυσική κλίμακα, σε ασφαλή επίγειο χώρο, κατάλληλα διαμορφωμένο ως επισκέψιμο για το ευρύ κοινό. Το σπήλαιο αποτυπώθηκε ταχύτατα αξιοποιώντας την τεχνολογία της τρισδιάστατης ψηφιακής σάρωσης laser. Σημαντικό ρόλο στην επιλογή των προδιαγραφών της αποτύπωσης διαδραμάτισαν οι αρχαίες επεμβάσεις στο μητρικό πέτρωμα του σπηλαίου Νυμφολήπτου καθώς και η τελική αξιοποίηση του τρισδιάστατου μοντέλου.

Abstract

The Cave of the Nympholept is located on the south side of Mount Hymettos and north of modern Vari. During antiquity, it functioned as a sanctuary dedicated to the Nymphs, Pan, Apollo, and, perhaps, Hermes. Its small vertical mouth was embellished with carved steps which are worn today. The creation of a new descent for the safe entering of visitors into the cave would demand at least a complete alteration of the original form of the cave mouth.

The purpose of the production of an exact full-scale model of the cave, located in a safe place suitable to function as a visiting site, was based on the detailed survey of the interior as well as the digital terrain model of the area. The cave was considered by 3D laser scanning. The final decision on the survey specifications was made according to the archaeological details and the idea of the 3D model simulation.

Λέξεις Κλειδιά/Keywords: Cave of the Nympholept, Vari, 3D laser scanning, 3D simulation model

1. Introduction

One of the most important caves of Attica used as a place of intensive cult since the 5th century BC is the Cave of the Nympholept, also mentioned as Cave of Pan or Cave of Archedimos (Fig. 1). The specific grotto preserves numerous elaborations upon its parent rock which establish it as a unique archaeological monument of universal value situated within Greek territory. It was a sanctuary dedicated to several deities who played a significant role on the lives of the women (namely the entering in adolescence, the phase of marriage, of conception and pregnancy, of giving birth and of raising children), but also on everyday life of shepherds and farmers too (for securing the fertility of their land and their flocks).

After the rise of Christianity, the existence of the cave was gradually forgotten. It was relocated again by Richard Chandler in 1765 and since then it became a favorite destination of all the Europeans who were crossing Attica while traveling to Greece and the Orient (Weller 1903, 264, note 2) in order to become acquainted with the place which gave birth to the ancient Greek civilization (Kokkou 1997).
An excavation lasting 10 days at the end of February 1901 was conducted by Charles H. Weller, archaeologist of the American School of Classical

Studies at Athens (Weller 1903, Wickens 1986, 90-121). It was then that the first plan and sections of the cave were drawn (Weller 1903, pls. I, II), while a second more detailed ground plan was published by the German archaeologists Schörner and Goette approximately one century later (2004, Beil. 3).

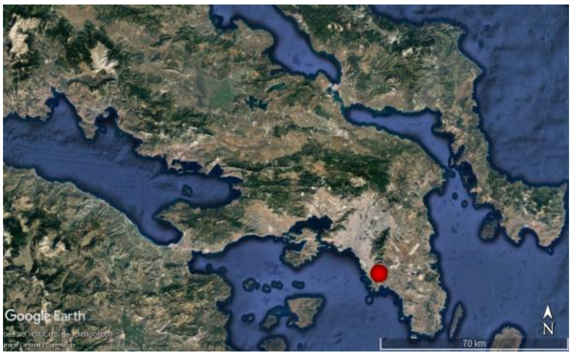

Figure 1. View of Attica with the location of the Cave of the Nympholept (Google Earth. Image @ 2018. Digital Globe).

The survey and documentation of a cave constitute an important part of its exploration. Classical as well as modern survey methods have been used during the past century in order to properly model caves of historical importance. The survey of a cave is a difficult task due to the special subsurface environment: the exact orientation of the cave is the initial quest. The usual survey methods have to be modified in order to fit the needs of the undersurface mapping of an archaeological monument which requires careful treatment and modified geodetic methods in order to attain the desired result.

The classical survey methods are divided into pure geodetic (Judson 1974, Dasher 1994) and photogrammetric ones (e.g. Chandler and Fryer, 2005). The main drawbacks of classical cave surveys are based on the large amount of time and resources needed in geodetic methods and on time consuming computation procedures of the photogrammetric. Traditional cave surveys utilize not very precise object representation techniques which are affected by errors due to the environmental conditions (Vouklari *et al.* 2017).

Terrestrial laser scanning (TLS) is an alternative modern technique for the exact representation of a cave (Παγούνης *et al.* 2004, Rüther *et al.* 2009, Tyszkowski *et al.* 2016, Vouklari *et al.* 2017). The appropriate manipulation of a large amount of data, the fast survey procedures, the quality of the representation, and the mapping resolution are the main advantages of TLS. In the case of a cave of archaeological interest, TLS can be used without any contact with the surveyed surfaces (geodetic techniques) and without establishing any special lighting installation (photogrammetric techniques).

The outcome of TLS is the point cloud of the observed object. The resolution of the point cloud permits the construction of a 3D model of the cave being studied. This model can be used in the representation of the monument in detail. Views, sections and cross-sections of the cave can be extracted from the final model.

Taking into consideration the morphology and the size of the cave, the present study will show how the survey of a monument with a 3D laser scanning can be used for the production of a 3D simulation full-scale replica at a safe visiting place.

2. The archaeological data

The Cave of the Nympholept is located upon the hill of Krevati, on south Mt. Hymettos (37º51΄29.31΄΄ N, 23º 48΄06.62΄΄ E), and belongs to the Municipality of Vari Voula Vouliagmeni. It is a cave formed within calcareous rock, with an almost circular ground plan comprising a vertical, inconspicuous entrance, at the W edge of which is formed a rock with a massive westward elongation that constitutes a partition between the two chambers of the cave: the dark, small north room, and the light, larger south room. It is interesting to note that the cave preserved a water spring on the west end of the northern chamber until a few decades ago (Weller 1903, pl. 1:ι).

As soon as one descends the flight of stairs carved upon the rock of the entrance, one lands on the east part of the north chamber where (upon the natural rock) the first ancient inscription is visible. The sign introduces us to the sacred place, embellished by Archedimos from Thera (probably the Cycladic island), who did all his work at the instructions of the Nymphs, because he was a nympholept. Being a nympholept meant that someone was possessed by the Nymphs and therefore he had the ability to communicate with them.

While crossing the north chamber westwards, there is a niche to the left with an inscription beneath, suggesting it was dedicated to Grace or Graces ("ΧΑΡΙΤΟ"). These were deities of fertility, responsible for all the nice things happening in people's lives and they were escorting most of the Olympian Gods (Κακριδής 1986, 279).

Before the niche of the Grace(s), a crudely made lion's head was visible until the first decades of the 20th century. The relief was depicted in Gell's and Monck's diaries after their visit to the cave in 1805 and is also mentioned by Dodwell (Dodwell 1819, 550-552, Schörner and Goette 2004, Taf. 20, Weller 1903, 269, 276).

Almost opposite of the niche of the Grace(s) stands another, scribbled inscription, giving strict injunctions to wash outside the cave the entrails brought as offerings to the gods (Schörner and Goette 2004, 44-46). A few meters after this inscription one sees to the right a carved water basin with a maximum depth of 0.815m, which maintains

"an inlet drain … cut at one end" (Weller 1903, 282), walls covered with hydraulic plaster, and a double leveled bottom with a circular shallow depression in the middle. The basin was suitable for purifications of the believers who would cross afterwards the rest of the small hall in total darkness which would generate intensive emotional charge and would prepare their souls for an elevation as soon as they came, through a carved threshold, into the biggest, light south room where the main cult would take place (Κύρου in print) (Fig. 2).

Figure 2. View of the south chamber of the Cave of the Nympholept, from W (K. Xenikakis 2017. Archive of the EPS).

Upon the west wall of the large south room is discernible a large human relief depicting Archedimos (stated twice by his carved name to the left), holding his pickaxe and his angle and moving to the right, with his head turned to the left, as if he is looking somewhere towards the northeastern part of the chamber. Beside him is a double altar carved on two levels which preserved an inscription destroyed during the last quarter of the 19th century as suggested by the drawings and the descriptions of the travelers of the time (Dunham 1903, 296, Schörner and Goette 2004, 47). According to these drawings, the altar was dedicated either to Apollo of the Dew ("ΑΠΟΛΛΩΝΟΣ : ΕΡΣΩ", see Weller 1903, 271, Dunham 1903, 296), or, most likely, to Apollo and Hermes ("ΑΠΟΛΛΩΝΟΣ : ΕΡΜΩ", where M might have been carved vertically or at an angle due to the lack of space. See Conor 1988, 182-183, Κύρου in print). Hermes, born in a cave by a Nymph, father of Pan, closely associated with Apollo in the eponymous Homeric Hymn (Kalligas 2017), leader of the Nymphs as depicted upon several marble votive reliefs, and protector of the herds (Spathi 2013, 407), fits perfectly well with the other gods honored in this cave.

One more carving (corresponding to another niche) is discerned on the north wall of the light chamber. With the exception of a sign ("ΣΠΗΛΑΙΟΝ ΝΥΜΦΟΛΗΠΤΟΥ") carved unfortunately on it, in the 20th century, it bears no element attributing it a specific function. However, it maintains a characteristic temple - like façade (Weller 1903, 267). The same applies for the biggest and best preserved altar, situated at the east part of the hall, beneath which can be read the word "ΠΑΝΟΣ" (of Pan). To the right of the altar of Pan is a carved three dimensional headless enthroned figure, which probably bore a head made from a different material, destroyed by Christians. Despite the fact that it is less than life-size, its elevated position (upon a low height platform) and the carved cuttings behind it for the placing of offerings, imply this figure played a central role to the cult. The existence of locks of hair on its shoulders presents no definite indication that the small statue depicts a female goddess as originally thought (Connor 1988, 185-186, Schörner and Goette 2004, 116-117, Weller 1903, 168-269). The fact that beside it, at a higher level, used to stand an omphalos appearing in the drawings of the travelers (Schörner and Goette 2004, Taf. 22: 2, 25:2, 28:2), but also in photographs taken before 1940 (Weller 1903, 268, fig.4, Παπαγιαννόπουλος - Παλαιός 1951, 79: eik. 2), has lead researcher Dr A. Kyrou (Κύρου in print) to suggest convincingly that the statue most likely depicted Apollo. God of light, patron of herdsmen and farmers, leader of the Nymphs (as evidenced in an inscription from the Corycian Cave, near Delphi), and protector of prophecy, Apollo was anyway one of the main deities honored in the cave. The interpretation of having a statue of Apollo fits also with the later use of the cave in the 4th century AD by followers of the neoplatonism who seem to have chosen this cave as a ritual place precisely because the god Apollo had already been worshipped there (Κύρου in print, Καλλιγάς 2017, 13-14: note 3, Kalligas 2017).

3. Previous surveys of the cave

Two classical surveys of the Cave of the Nympholept were carried out during the past years. The first effort was performed in 1901, using classical methods (obviously compass, measure tapes, triangles), and produced a plan upon which all the carved details are indicated by a Greek letter (Weller 1903, pl. I).

It is interesting to note that in the specific plan the main hall is located on the south part of the cave with a downward slope towards the west. According to the graphic scale, the total area of the cave is approximately 250 m^2. Two cross-sections were also depicted (Weller 1903, pl. II, also reproduced in Schörner – Goette 2004, abb. 1). Their horizontal graphical scale implies a 20 m maximum distance of the cross-section in the North-South direction. Unfortunately, no further information on the vertical scale is provided and thus there is no data concerning the height mapping of the cave.

Another topographical plan of the monument was published by Schörner and Goette in 2004 (Beil. 3). For the survey of the cave, classical geodetic instrumentation (theodolite) was used (H.R. Goette, personal communication 2018). The surveying procedure was integrated on the field in 2000 during one week. The final drawings were re-processed by an architect based on in-situ measurements and photographs. Compared to the 1903 plan, the 2004 survey mapped a slightly different geometry of the cave. First of all, the area based on the graphic scale is estimated approximately 300 m^2. In addition, the orientation of the cave is completely different to the one presented in Weller 1903: the main hall is depicted on the eastern part of the 2004 plan while the second room lies in the western part of the cave. The totally different result following the above-mentioned surveys and the need for an exact simulation model of the cave led to the TLS survey procedure adoption.

4. The TLS survey procedure

4a Network establishment

Due to the special cave environment a control base was established near its entrance. This base was referenced to the Greek Geodetic Reference System 1987 (GGRS1987) using GPS satellite observations and the Hellenic Positioning System (HEPOS – Gianniou, 2008) as reference network. The receiver Magellan ProMark 500 RTK System was used providing cm accuracy in the position. Given the orientation of the base, 20 new stations were created inside the cave at the location of the desired laser scanner sites (Fig. 3). The loop closure residuals of the closed transverse were computed at the level of 3˚ in the angle and 3mm in the distance measurements. The height residual was calculated at the sub-mm level.

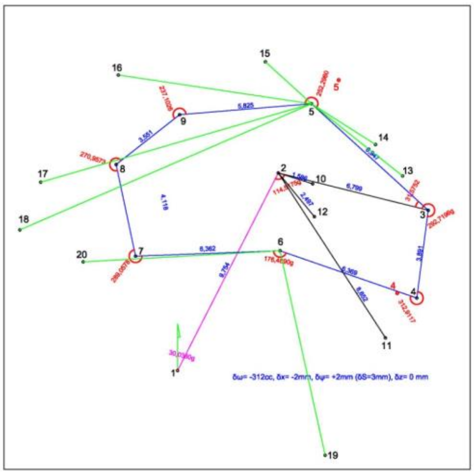

Figure 3. Cave of the Nympholept. Diagram of the control network and the stations of the laser scanner.

4b Cave scanning procedure

A cave as a scanning object needs special treatment due to the large amount of survey details. Additionally, the environment inside a cave is not ideal for scanning procedures: humidity, low lighting, high inclination and slippery floor are the major problems dealt with during a cave mapping. The scanning of the specific cave was performed with a Leica Scanstation 2 TLS and the appropriate ancillary equipment (target spheres etc). Leica Cyclone © software was used in the data collection and the point cloud processing. The method of direct georeferencing was used during the scanning procedure. This means that due to the known coordinates of each station, the georeferencing of all independent scans was achieved as well as their registration in a common system. In this way, the scanner was set up over a known point (and its height over the point measured), it was centred, levelled and oriented towards another known target where a spherical reflective target of known diameter (15 cm) was used as backsight mark, like a total station. The acquired scans taken from multiple scanner stations were already in the same reference system and were easily merged into one dataset. The spherical reflective targets were scanned with an accuracy of 1-2 mm and the RMS error of the direct georeferencing was in the order of a few cm.

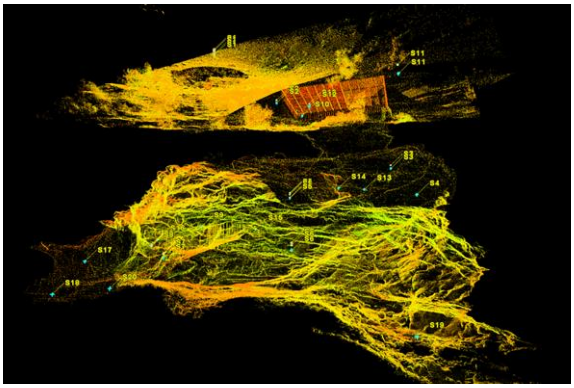

Figure 4. Cave of the Nympholet. The final point cloud.

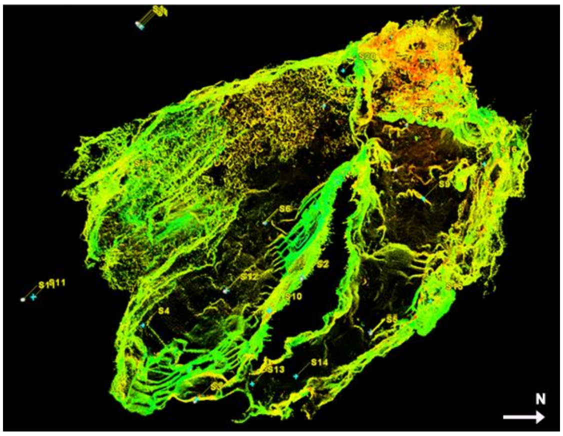

Figure 5. Cave of the Nympholept. Top view of the point cloud

A resolution of 1 cm was chosen as basic scanning setup, while 1 mm was decided for the important historical details of the cave. The horizontal range of the scanning was set from 0° to 360°, while 0° - 270° was the range on the vertical direction. The archaeological details were scanned in a special procedure using the maximum resolution. The duration of each scan was approximately one hour. An effort was made to maintain short distances (up to 10 m) between the scanner and the object in order to fully cover the cave walls. In Fig. 4 the final point cloud is shown where the entrance and the shape of the cave are clearly depicted.

The top view of the point cloud can be seen in Fig. 5. The two halls, some of the set-up stations chosen for the scanning procedure, and the shape of the cave are clearly presented.

4c 3D model creation

Before the reconstruction of the 3D model, all the unwanted information (e.g. plants and moisture) called noise, which interferes in the final object mapping, has to be reduced, i.e. manually removed, from the point cloud. This task is time consuming but very critical in the modeling procedure. A noisy point cloud can lead to a 3D model with blunders and spikes that do not represent the survey object. Another important issue is to fill-in the gaps of the scanning. This can be done by an interpolation procedure through triangulation. The point-to-polygon (mesh) process is a very sophisticated and resource intensive one, even for specialized 3D modeling software and still under research investigation. In the present study, the final point cloud was imported into 3D SYSTEMS GEOMAGIC © software in order to be modeled properly. The initial 3D model of the cave is constructed by converting a number of given points into a consistent polygon format (mesh). The spikes of the initial phase are removed using a smoothing – interpolation algorithm. In addition, the gaps of the initial meshing procedure were filled in manually by a re-triangulation method through GEOMAGIC (Mesh Doctor and RE-mesh procedures). The final 3D model of the cave is presented in Fig. 6.

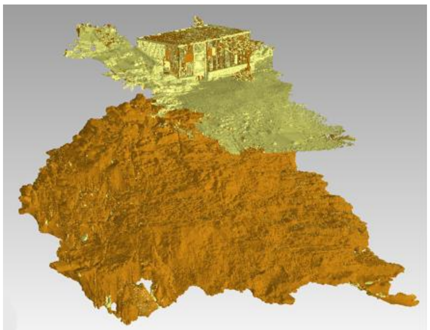

Figure 6. Cave of the Nympholept. The final 3D model (in yellow: the surface features. In orange: the subsurface details).

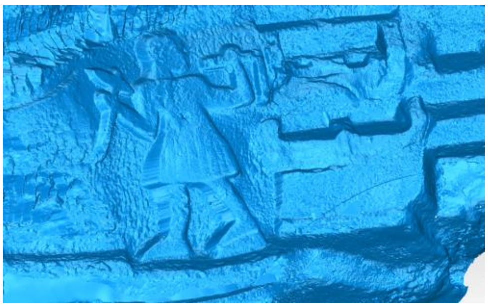

Figure 7. Cave of the Nympholept, south chamber. Model of the figure of Archedimos and of the altar of Apollo.

As mentioned above, a number of sculptures and inscriptions were chosen to be modeled using the TLS procedure with a fine resolution of 1 mm for the proper identification of the carvings. These archaeological features are isolated from the complete model in order to be mapped in detail.
The 3D models of the carved figure of Archedimos, of the altar of Apollo and Hermes, of the altar of Pan and of the headless statue are presented in Figs. 7- 9.

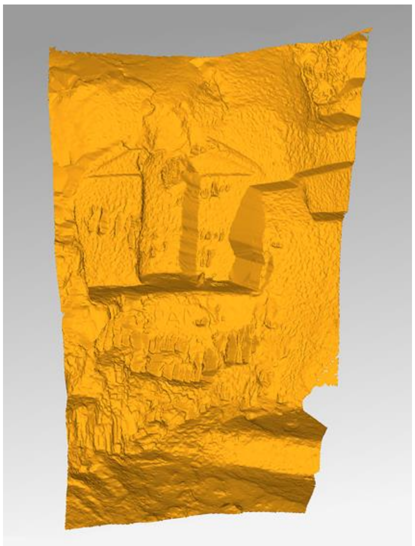

Figure 8. Cave of the Nympholept, south chamber. Model of the altar of Pan.

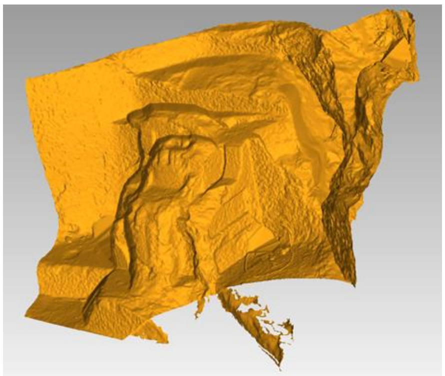

Figure 9. Cave of the Nympholept, south chamber. Model of the headless statue.

4d Photorealistic features and video

The texture map of the features of archaeological interest was based on photographs taken (by K. Xenikakis) inside the cave using professional cameras and using various light conditions. Nevertheless, the information imported from the photos enriched the 3D model with the specific texture map of the object's detail. The image manipulation was performed using GEOMAGIC © software in an automated manner. The texture map was constructed using the registration procedure of common points. The final photorealistic objects contain the metrics from the modeled point cloud and the texture from the embedded photos (Figs. 10-13).

Figure 10. Cave of the Nympholept, south chamber. Detail from the texture map of the carved figure of Archedimos and of the altar of Apollo and Hermes.

Figure 11. Cave of the Nympholept, south chamber. Detail from the texture map of the altar of Pan.

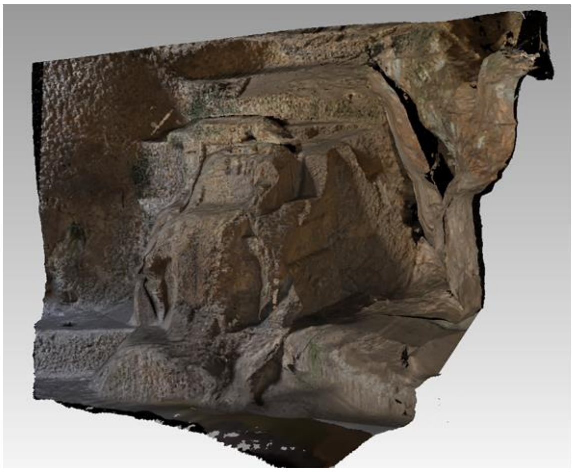

Figure 12. Cave of the Nympholept, south chamber. Detail of the texture map of the headless statue.

Figure 13. Cave of the Nympholept. Texture map of the first inscription in the north chamber.

4e Section and cross-section plans

The main parameters used to define a line section are (Vouklari 2017):

- *Thickness*, to define a volume around the plane where points are selected and possibly projected on it
- *Tolerance*, to control noise and alignment problems of different point clouds
- *Length*, for the minimal measure of the constructed segments
- *Distance*, which has to be minimal among the selected points.

Many studies deal with this subject. In some cases, the construction of a 3D model relies on a sequence of many nearby sections. The same method is applied to mechanical or freeform objects (e.g. Kyriazis *et al.* 2007) with the goal of representing a generic shape, in the best possible way.

In this study, the main axes chosen for the section and cross-section plans relied on the GGRS87 reference system. The choice of a georeferenced section plan was decided in order to have a link to the final simulation model of the cave. Autodesk AUTOCAD © and Leica Cloudworx © menu were utilized in the point cloud manipulation and section plans. A grid spacing of 1 m was chosen in Z direction and 13 section plans were created. In addition, cross-section plans of 1.5 m resolution were created (Fig. 14). The area of the cave as computed considering the section plans were estimated approximately 270 m^2. As far as the cross-section plans are concerned, the height difference from the bottom of the cave to the surface is approximately 13 m, and specifically from 266 m above MSL (Mean Sea Level) to 279 m above MSL. The heights are referenced to the Hellenic Vertical Reference System; its zero level was estimated by tide-gauge observations of 18.6 years at Piraeus harbor (Mylona-Kotroyianni 1989).

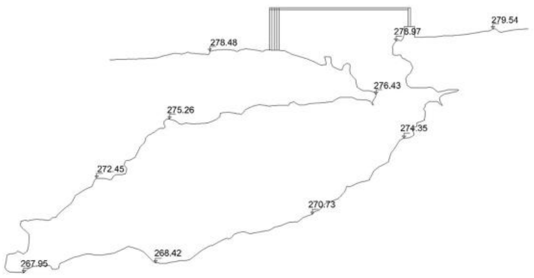

Figure 14. Cross section (no 8) of the Cave of the Nympholept.

5. Proposal for the construction of a replica

Requests of people to visit the Cave of the Nympholept increase day by day as they realize its uniqueness. However, the danger comprised in the attempt of descending the ancient narrow and worn steps of the entrance, having to confront a gap, approximately 6m deep, next and to the south of the steps and another one 3m deep to their north, designates the exclusion of most of the potential visitors.

A possible construction of a modern flight of stairs on top of the ancient ones, made of stainless steel (ISCA *et al.* 2014, 10) and having a protective balustrade, seems to be out of the question since it would involve an alteration of the original form of the cave mouth definitely affecting the archaeological character of the monument. Moreover, according to the recommendations of the Adjunct Secretary of the International Union of Speleology, the official opening of a show cave to the public should offer the possibility of access to people with reduced mobility (Bartholeyns 2016). In our case such a project would be equivalent to a complete destruction of the small vertical entrance whose opening measures 4.0 m length X 2.0 m width.

On the other hand, keeping tourists away from the original site seems to mean less damage of this persistently harassed monument which actually deserves better treatment (Κύρου in print).

The application of a 3D virtual tour should not be ruled out since it can offer quite satisfactory results by allowing people to "get" inside and "wander" within the monument. Depending on the concept of the tour, it might also help people have a virtual reconstruction and thus visualize how this cult place might have functioned in antiquity. Yet, this one seems to be a compromise which cannot offer the visitor a complete sense of the dimensions of the cave and of its carvings.
Therefore, the possibility of constructing a full-scale model of the cave at a suitable visiting place should be taken into serious account as an ideal solution.

An excellent example of a similar case constitutes the Chauvet cave discovered in 1994, in south France. It constitutes a magnificent monument with an area of approximately 20.700 m². Upon its walls are preserved the most ancient drawings of various painted, drawn or engraved animal species, dated between 32000/30000 BP and 27000/26000 BP (Clottes 2003). The French authorities had to confront various problems: the blocked prehistoric entrance; the destabilization of the ancient stalagmitic structures in the first chamber; the need for ongoing study of the cave by scientists; and, most of all, the fragile nature of the drawings along with the fear of causing damage and pollution to the cave which is a UNESCO World Heritage site. Thus, they decided to proceed to the building of a full-scale replica so as to be used as a visiting site. The replica leans against a modern metallic frame. The construction of its walls was accomplished with the use of 6.000 digital images (which were overlapped in developing sketches), and with the collaboration of sculptors, painters and blacksmiths. In this way, this special visiting place was ready within three years and opened at the nearby cave Pont D' Arc, in spring 2015. The site comprises half of the area of the Chauvet Cave and constitutes the largest replica of cave in the world (www.dailymail.co.uk/travel_news/article-3009681/ Replica-Chauvet-Pont-d-Arc-Cave-open-France. html).

The "Lascaux 4" is another well-known replica housed in a half-buried building of concrete and glass unveiled in 2006 (https:/ /phys.org/news/2016-12-france-lascaux-prehistoric-art-cave.html). It replicates the dimensions, the artwork and colours of the original Lascaux Cave, in southwest France, which preserves on its walls prehistoric art estimated to be up to 20000 years old (Lima and Psaila 2012).

Other replicas of caves include parts of the Cave of Altamira in Spain with paintings which seem to date between 14000 and 22000 years ago (https://www.nytimes.com/2014/07/31/arts/international/back-to-the-cave-of-altamira-in-spain-still-controversial.html). Caves like those in Dunhuang western China (Mogao Caves), the Yungang Grottoes near Datong city in Shanxi – Shanghai, and the Ajanta and Ellora Caves in Maharashtra state of India, constitute monuments with paintings and/or rock-cut sculptures of a much later date (see for example www.getty.edu/ conservation/ publications_ resources/ newsletters/31_1/peerless_caves.html, https://medium.com/shanghaiist/look-3d-printed-replicas-of-buddhist-statues-from-the-yungang-grottoes-9ae657fa1866, and https:///timesofindia.indiatimes.com/city/pune/Tourist-centre-to-house-replicas-of-Ajanta-caves/articleshow/15358809.cms respectively).

In the case of the Cave of the Nympholept, things would be rather easy because of the small size of the cave (around 270.0 m²), which would imply less time and cost for the realization of such an ambitious but feasible project. The Cave of the Nympholept does not preserve paintings but rock-cut carvings and sculptures, difficult to be harmed by people exhaling carbon dioxide. It should be mentioned though, that the loss of humidity due to the open entrance and to the various environmental and other changes, transform gradually the crystalline calcium carbonate of the cave into amorphous calcium carbonate, and thus, cause damage to the carvings (V. Giannopoulos, personal communication). Additionally, there is always the danger of cyanobacteria which grow not only upon the surface of the sculptures but inside them as well because of the light entering the cave through its vertical entrance (Pantazidou *et al.* 2012, 264). By creating a replica, we will gain the protection of the original cave and its preservation for the future generations. At the same time we will offer the opportunity to people of different ages, not related to athletic speleology, to learn about and admire the work of a man who lived 2500 years ago and invested a lot of time and labour for embellishing this important sacred place.

It should be stressed that the Ephorate of Palaeoanthropology – Speleology accepted during the previous years to guide groups of people asking for permission to visit this cave, so as to develop gradually the awareness of the public of the cultural and historical significance of this irreplaceable archaeological monument and of the necessity for its safeguarding. However, since 2017, permission to visit the cave is only granted to speleologists, archaeologists and students of archaeology, in order to minimize the possible risk of accidents. Other groups of people wishing to visit the cave are encouraged to accept guiding outside the entrance of the cave with the use of educational material (maps, coloured photographs, ground plans and drawings).

In our opinion it is about time to proceed to the creation of a replica, having in mind that we can borrow the relevant know-how and the necessary experience by the specialized technicians of other countries who have already worked upon such undertakings. The location of a proper place, at a close distance, upon Mount Hymettos, whether it might be a natural cave or a built subterranean artificial one to house this special site, should not be assumed a difficult issue. Simulated stone face plaster or resin might be used to represent the natural rock, the speleothems (stalagmitic material) and Archedimos' carvings. The contribution of specialized sculptors, who will collaborate with photographers, engineers, and various technicians, is considered substantial.

The entrance of the replica might be constructed in a wider version for the addition of a small elevator for people with special needs. The flight of stairs might have on the north side a protective metal handrail whereas the deep gap at the south side might be covered with a transparent unbreakable material. Due to the small dimensions of the north chamber, a single pathway which will be used as the walking surface for the visitors will be adequate along with a couple of broader areas where a small group could be gathered to listen to a guide or enjoy the scenery (cf. ISCA *et al.* 2014, 9).

6. Conclusions

The Cave of the Nympolept constitutes an important cult place, possibly functioning as such from the beginning of the 5th century. It was embellished by Archedimos with carvings, inscriptions, reliefs and a statue, after 450 BC (Schörner and Goette 2004, 107). His name was inscribed four times upon the walls of the cave, twice upon a loose stone block and once upon a fragment of a marble stele (Κριτζάς 2001, 19-20), testifying for the decisive role he played in transforming the cave into a special sanctuary dedicated to several gods.

The uniqueness of this cave created the need for its exact representation by using terrestrial laser scanning (TLS). TLS provided a permanent digital record, which can be of primitive importance in the future conservation and restoration of the monument. Moreover, it produced the maximum detail and the metrically accurate dataset in order to acquire the 3D model of the cave which can and should be used for the development of a full-scale replica that will function as a visiting site.

For its construction, assistance can be offered by countries which have already completed similar projects [see paragraph 1, article 13, of the *World Heritage Convention of the General Conference of the United Nations Educational, Scientific and Cultural Organization meeting in Paris from 17 October to 21 November 1972, at its seventeenth session*. Also: article 12 of the *Confirmation of the European Convention on the Protection of the Archaeological Heritage (revised)* (ΦΕΚ 203/Α/19-8-2005)].

In this way we will gain an impressive visiting site of main attraction, offering information of great archaeological value.

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HISTORIC BUILDING INFORMATION MODELING ON SITE

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Περίληψη

Αυτή η εργασία παρουσιάζει τη μεθοδολογία για τη δημιουργία πληροφοριών μοντέλων ιστορικών κτιρίων (HBIM) από τη νέφη σημείων από σαρωτή λέιζερ και φωτογραμμετρίας. Η τρισδιάστατη μοντελοποίηση πραγματοποιείται λαμβάνοντας υπόψη τις απαιτήσεις του τελικού HBIM που βρίσκονται σε κινητές συσκευές, οι οποίες έχουν περιορισμούς με μεγάλα και σύνθετα μοντέλα. Αυτά τα μοντέλα θα μπορούσαν να έχουν πολύ υψηλό επίπεδο λεπτομέρειας, με αποτέλεσμα να υπάρχουν προβλήματα μνήμης όταν χρησιμοποιούνται σε κινητές συσκευές όπως smartphones και tablet. Η εργασία στοχεύει στην επίδειξη ενός λεπτομερούς μοντέλου HBIM το οποίο μπορεί να απλοποιηθεί και να χειριστεί σε κινητές συσκευές, έτσι ώστε το μοντέλο να μπορεί να απεικονιστεί από το γραφείο στο χώρο αποκατάστασης.

Abstract

This paper presents a workflow for the creation of historic building information models (HBIM) from laser scanning and photogrammetric point clouds. 3D modeling is carried out considering the requirements of the final HBIM handled in mobile devices, which have limitations with large and complex models. Such models could feature a very high level of detail, resulting in memory issues when used in mobile devices such as smartphones and tablets. The work aims at demonstrating that an accurate and detailed HBIM can be simplified and handled in mobile devices so that the model can be moved from the office to the restoration site.

Λέξεις Κλειδιά/Keywords: Augmented Reality, BIM, Laser Scanning, Photogrammetry, Virtual Reality

1. Introduction

Mobile devices (smartphones, tablets) are used for productive work in different disciplines. They are not only tools able to connect people, but also portable solutions for productive work.

This contribution aims to prove that a detailed HBIM (historic building information model) handled in mobile devices is an opportunity for the specialists of the Architecture, Engineering, and Construction (AEC) industry as well as the specialists in the field of cultural heritage documentation and preservation. This work aims at demonstrating that an accurate and detailed accurate HBIM generated from point clouds can be handled with portable devices (mobile phones and tablets) and specific mobile applications based on BIM technology, combining cultural heritage conservation and preservation policies and technical work with new technologies. The different specialists involved in the project can exploit the advantages of an improved collaboration based on BIM projects with their portable tools connected to a cloud service.

Examples of mobile applications integrating BIM technology were proposed in Waugh et al. (2012), in which an augmented environment was developed to document construction progress. In Dunston and Wang (2005), an augmented reality tool was designed to support all phases of the facility life cycle. Park et al. (2013) presented a conceptual framework that integrates augmented reality with BIM to detect construction defects.

In the case of BIM, specific mobile applications able to handle 3D models are already available on the Internet. Google Play and Apple Store offer different applications supporting BIM, augmented reality, virtual reality, 2D and 3D CAD, etc. Examples are Autodesk 360 mobile, Buzzsaw Mobile, Tekla BIMsight Mobile, Graphisoft BIMx, SketchUp viewer, BIManywhere, Structural Synchronizer, McNeel iRhino, LCi Sightspace3D, BIM 360 Glue, Navigator Pano Review, Revizto Viewer, Inframeworks 360, among the others.

The integration of detailed HBIM in mobile devices is not a trivial task. Very detailed digital models (the aim is to avoid simplified models not useful in real projects) are here considered as well as their operational use in handheld mobile devices. HBIM technology needs parametric models with a level of detail better than traditional models for modern construction projects, which are based on sets of predefined object libraries. Additional issues in HBIM arise concerning memory occupation, making the exploitation of the model more complicated in mobile devices than traditional desktop solutions. As parametric models (with an associated database) are usually generated in the office with desktop-based solutions, the reuse of such models in mobile devices could require a substantial simplification of both geometry and information.

Different authors proved that the creation of a detailed HBIM of a historic building is challenging with commercial sw packages (Fai et al., 2011; Murphy et al., 2013; Brumana et al., 2013, 2014; Oreni et al., 2014a) revealed by laser scanning and photogrammetric point clouds. In addition, BIM is based on objects with relationships to other objects, attributes, and parametric modelling tools. Semantics is important during the generation of specific parametric objects of historic constructive elements, which can require the creation of ad-hoc libraries and the development of new procedures for parametric modeling.

The work investigates the full workflow for HBIM generation in which the starting point of the project is the acquisition of laser scanning and photogrammetric point clouds. The HBIM is generated with semi-automated measurements, in which user interaction is still fundamental to separate the different structural elements and create a model based on constructive elements.

The case study presented in this paper is Castel Masegra, a castle located in Sondrio (Lombardy, Italy). A detailed historical HBIM (the model is about 500 MB in Revit) was created from laser scanning and photogrammetric point clouds (7.5 billion points). The generation of the final HBIM was carried out by dividing the different structural objects according to their constructive logic. Chronological, material and stratigraphic aspects were also taken into account for the complexity of the various parts that form the castle. This phase is also useful for finite element analyses (Barazzetti et al., 2015b) where the modifications occurred over time are extremely important to understand the castle and its logic of constructions. The model was then exported and converted into several formats to exploit the possibility offered by the available portable applications. The use of the procedure proposed by Barazzetti et al. (2015a) was used to avoid excessive simplifications resulting in models not useful for conservation. Finally, the BIM was turned into a new version for mobile devices, in which technical data were included to support restoration and conservation projects.

Figure 1. Castel Masegra in Sondrio.

2. Data acquisition and processing

The complexity of Castel Masegra required the integrated use of photogrammetry and laser scanning techniques for the geometrical survey. A geodetic network was used to provide a stable reference system for scan registration and image orientation. The measurement phase of the network required four days. The instruments used was a total station Leica TS30 (distance precision 0.6 mm, angle precision 0.15 mgon). In all, 68 stations form the network shown in Fig. 2. Geodetic tripods were not moved (repositioned) during the survey to increase geometric accuracy. In all, 4,622 observations and 1,402 unknowns gave 3,220 degrees of freedom and least squares adjustment provided an average point precision of about ±1.2 mm. Measurements were taken including not only station points, but also some fixed points (mainly retro-reflective targets) and chessboards targets for scan registration.

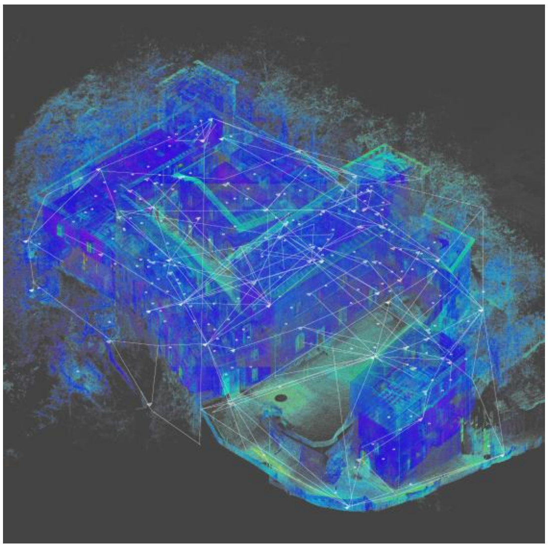


Figure 2. Total station network for Castel Masegra

The size of the castle required 176 laser scans registered in the reference system of the geodetic network. The laser scanning used is a Faro Focus 3D. The consolidated final point cloud (i.e., the union of all different point clouds through registration) has more than 7.5 billion points (Fig. 3). Scan acquisition took 5 days. Scans were registered with an average precision of ±3 mm by using chessboard targets measured with the total station and additional scan-to-scan points (spherical targets). After scan acquisition and registration, the survey was integrated with some other scans to capture also occluded areas detected after the first surveying phase.

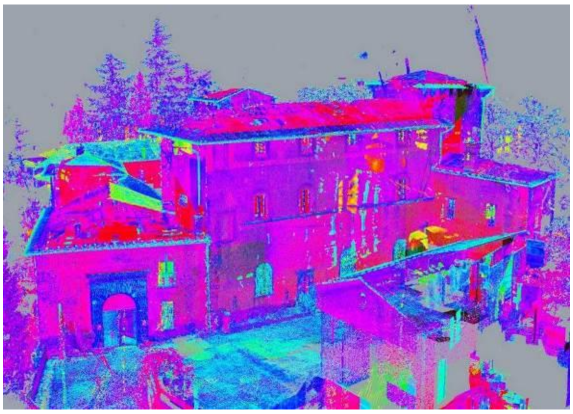


Figure 3. The laser scans acquired in Castel Masegra

The limited time for scan acquisition (less than a week for the large and complex case study presented in the paper) proves the level of maturity reached by modern laser scanners. It is clear that the time needed for data processing (especially HBIM generation) is instead more significant, especially in the case of very detailed reconstructions.

Photogrammetry was used to integrate the reconstruction of specific elements, mainly where a high level of detail was necessary. Different digital cameras with different lens were processed with both Agisoft Photoscan and PhotoModeler. Finally, an aerial block acquired with a drone (Asctec Falcon 8) gave useful images for the reconstruction of the roof. Images were extremely useful to extract dense point clouds which integrated the laser scanning dataset. Images were used to create high-resolution orthophotos (e.g., the North facade in Fig. 4). Measurements acquired with the total station data were used as a reference to register all data in the same Cartesian system.

Photogrammetry and laser scanning can reveal the external surfaces (i.e., the visible surfaces) of objects, whereas an HBIM is made up of solids with an internal structure. As the goal is the creation of an interoperable HBIM and its operational use between the different operators that work on the castle (engineers, architects, historians, archaeologists, restorers, etc.), the survey was integrated with historical analysis, materials, construction phases, technological aspects, stratigraphic analysis, and information from other inspections such as infrared thermography or structural tests (flat-jacks, coring, etc.).

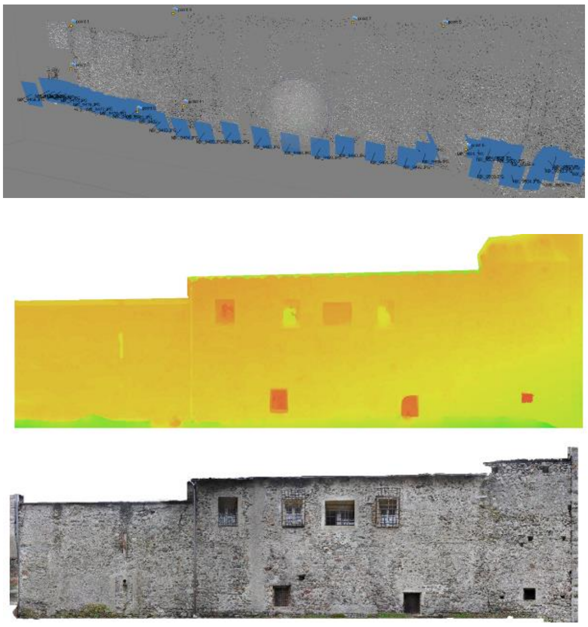


Figure 4. Generation of a detailed orthophoto of the North wall.

3. Creation of the historic BIM

The 3D model of the castle provides the geometric-constructive-morphological and structural complexity of the whole structure. The modeling process was carried out with data obtained from the survey and historical, material and stratigraphic information. A 3D model was created taking into account the different structural elements (vaults, beams, walls, columns, etc.) and their logic of construction. Methods based on the direct interpolation of the points with a mesh were not taken into account to avoid heavy models (without parametrization) that do not follow the constructive logic of the castle. BIM is much more than geometry. It is a dynamic database of the building with improved coordination of construction documents where geometry, spatial relationships, geographic information, and other quantities or properties of building components are structured.

The generation of the HBIM described in this paper is carried out by considering some requirements of the project. First, the HBIM is intended as an interoperable tool able to manage different steps of the restoration (diagnostic analysis, finite element analysis, LCA/LCM, economic analysis, …). Different operators should be able to use the information of the model (interoperability). Secondly, the HBIM is not a “crude” 3D model useless for restoration/conservation processes: the constructive logic plays a fundamental role during the modeling phase. Lastly, the geometric part takes into account the complex shape of the objects (according to the scale of representation) along with object attributes (materials, deterioration, etc.).

The starting point for the generation of the HBIM is the set of dense laser scanning point clouds which reveal the geometric complexity of the castle. As mentioned, a complete HBIM must follow the basic requirements of BIM projects. The creation of the model cannot be carried out with direct modeling techniques (e.g., the interpolation of the point cloud with algorithms able to provide a mesh) usually used in image-based and range-based modeling projects. The word “information” plays a fundamental role in a complete HBIM project (e.g., materials, construction stages, stratigraphy, and other attributes). Semantics has to be taken into account to create parametric objects with relationships to other objects.

Photogrammetric and laser scanning measurements are therefore powerful tools for the generation of surfaces, but a more exhaustive analysis of the building must be carried out to integrate geometric information. Surfaces are not sufficient for BIM. Complete elements (i.e., those not limited to external surfaces) are necessary for a complete HBIM. The use of other techniques (e.g., infrared thermography) allows the inspection and analysis of the constructive logic of constructive elements. Architectural and structural interpretation is mandatory to represent the different elements and their connections correctly.

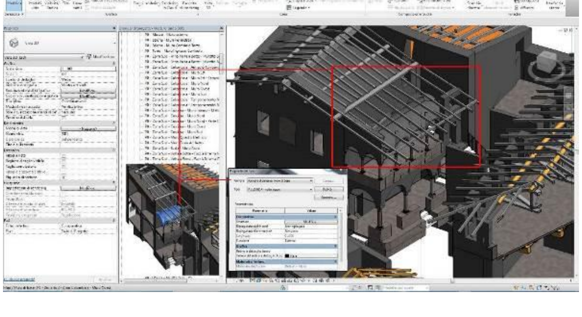
The generation of an accurate HBIM also has a direct impact on the method for 3D modeling, which cannot be based on the creation of predefined static shapes, like simple solids (planes, spheres, cylinders, and so on) or models based on meshes. Parametric modeling requires a new dynamic modeling concept where objects can be edited and modified without redrawing: the shape is related to a (finite) number of geometric quantities that can be numerically changed.

Historic documents and existing reports were studied to identify the stratigraphic layers and the different construction stages. This means that the HBIM can provide a visualization of the changes and modifications occurred in the past. From this point of view, the use of an HBIM is a valid tool for the possibility to modify initial hypotheses without creating a new model. Different construction stages can be set in the database and interactively changed when further information is available.

Different strategies for parametric modeling were used for the different constructive elements of the castle. First of all, objects were divided into “simple” and complex” elements. “Simple” objects are those for which the modeling tools available in commercial software (Autodesk Revit in this case) were sufficient for accurate reconstruction. The situation of irregular objects (e.g., vaults, arches, etc.) is instead more complicated for the lack of commercial solutions for parametric modeling able to create detailed models using laser point clouds (Eastman et al., 2008; Lee et al., 2006). For this reason, the procedure proposed by Oreni et al. (2014b) and Barazzetti et al. (2015a) was used to create parametric BIM objects based on surfaces made up of NURBS curves and NURBS surfaces (Piegl and Tiller, 1999).

Some images of the final HBIM (available in Revit file format) are shown in Fig. 5. The BIM is made up of different objects: walls, vaults, columns, ceilings, beams and trusses, stairs, decorations, etc. Structural elements were classified following the predefined structure of the software database: category, family, type, and instance. 3D modeling was carried out from slices and 2D drawings created from the laser cloud. The preliminary use of 2D technical drawings is a valid tool to distinguish areas where an accurate 3D modeling is required for parts that can be simplified with predefined objects. Plans, sections, and elevations correctly positioned in the reference frame for the reconstruction of the model. This is a fundamental point for the creation of an accurate BIM consistent with the preliminary products of the geometrical survey.

Starting from plans and sections, the major deviations from verticality of exterior walls were identified, whereas the interior wall appeared reasonably vertical. Revit tools for openings (“windows” or “doors”) were not directly used because of the lack of correspondence between predefined libraries and the real objects of the castle. Although the basic functions of the software allowed one to define a large number of predefined parameters, a minimal correspondence was found for the complex openings of the castle. The accurate modeling of wooden frames required the definition of ad hoc families for the different types of openings. For this reason, the openings were modeled as “voids” in the BIM. Future work will consist of a survey with a superior level of detail of the opening and the creation of ad-hoc objects.



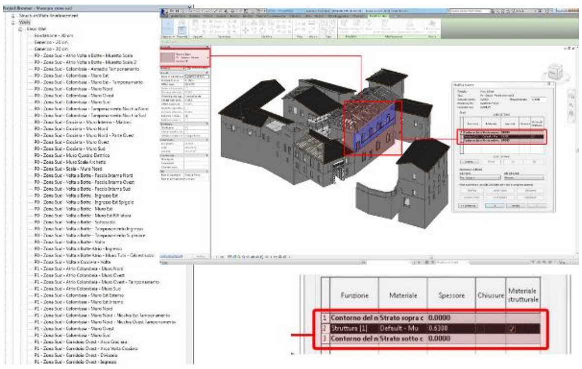


Figure 5. The final BIM in Autodesk Revit.

4. HBIM in the field with portable devices

Mobile BIM applications allows the visualization of the 3D model in the field. On the other hand, this process is not only intended as the visualization of a "crude" 3D model. BIM technology allows us to associate information to the different objects forming the BIM. This information can be exploited in the construction site with various portable devices (mainly smartphones and tablets).

Mobile BIM has a strong connection to cloud-based technology. A centralized version of the project can be accessed with mobile applications, obtaining a simultaneous connection of multiple users without delivering multiple project versions with possible inconsistencies (the case of multiple copies of the same file). Real-time communication can be carried out between different specialists through messages and email notifications. Such services are already available in some cloud-based platforms, allowing multiple specialists to work inside a highly collaborative environment.

The first application tested in this work was Autodesk 360 (A360), which can handle BIM projects generated in Autodesk Revit. Different specialists can exploit the advantages of such applications, which offer a dynamic visualization of 2D and 3D drawings. On the other hand, A360 is not only a viewer of geometric reconstructions. It is a powerful tool to visualize and inspect BIM projects, including object properties and reports of the different activities.

An HBIM project in Revit can be saved in a new DWF file format which preserves objects information. Different visualizations (3D views, sections, plans) can be set in the project to facilitate access to the different parts of the model in A360. Although some problems were found with object textures, A360 allowed an efficient visualization of the large Revit model of the castle (more than 500 MB) thanks to a preliminary conversion in the DWF file, without losing object information. The opportunity to preserve information encapsulated into the original BIM is an essential concept. This avoids the creation of 3D models based on simple geometry, in which additional attributes (e.g., materials, thermal properties, etc.) is not available. Fig. 6 and fig. 7 illustrates some of the basic operations that can be carried out with A360. As can be seen, the use of the model is not limited to the virtual navigation with interactive tools (zoom, pan, rotate). 2D drawings (sections and plans) are available on-site without printing project boards. Material properties and additional information (e.g., the construction stages of the castle) can also be virtually inspected.

The availability of digital information "in the field" will not substitute traditional project boards, which remain mandatory in real construction and conservation projects. On the other hand, a BIM handled in mobile devices opens new opportunities for better exploitation of digital technologies, offering new instruments that can improve and integrate the traditional work carried out in the field.

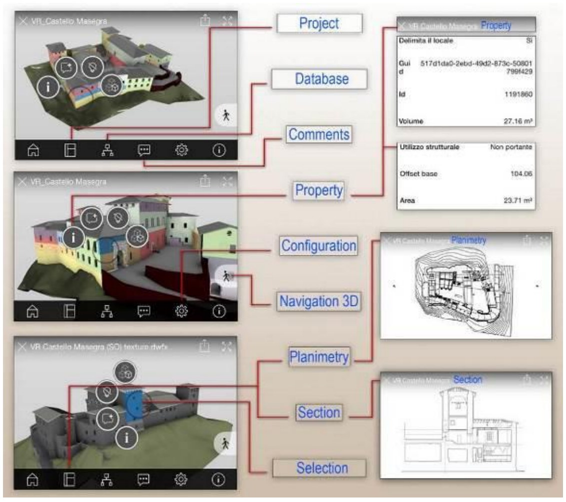


Figure 6. The use of the HBIM with an iPad allows interactive visualization. Queries can be easily carried out in the field.

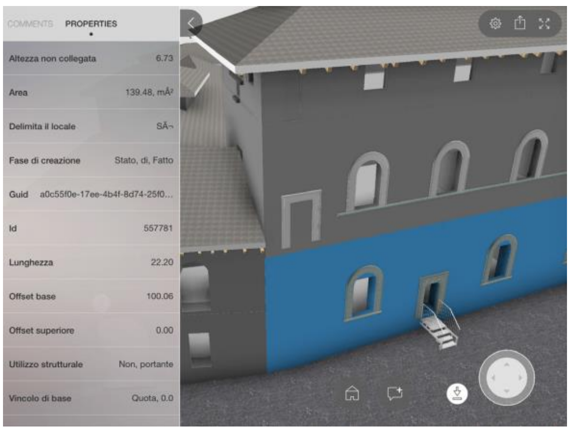


Figure 7. The BIM of Castel Masegra inspected with A360 on a tablet. The software preserves object information.

Another application tested in this work is BIMx (Fig. 8), which is the mobile application associated with ArchiCAD. BIMx is another app able to preserve information during the conversion of the BIM project from the desktop-based version to the portable file format.

The model of Castel Masegra in BIMx is very fluid, with the opportunity to create dynamic sections. This allows the generation (in the field) of an infinite number of plans or sections. BIMx cannot open Autodesk Revit models in the native Revit format. The 3D model of Castel Masegra was converted into IFC format. The IFC file was then imported in ArchiCAD. Information shared between two BIM software resulted in some errors during the conversion of particular objects, including an information loss especially for CAD blocks, object textures, and some material properties.

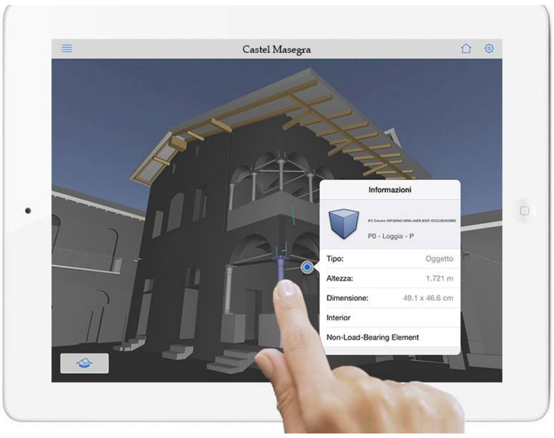


Figure 8. The model imported in BIMx lacks some information available in the original BIM.

The availability of interoperable file formats is a fundamental requirement to ensure the use of the model in different software platforms. The goal is a practical solution for the various specialists involved in the project. Standards and procedures in BIM should ensure the interoperability between different commercial software. In particular, the format used to describe, exchange and share BIM information is IFC (Industry Foundation Classes), developed and maintained by buildingSMART International and registered with the International Standardization Organization ISO as ISO16739. Nowadays, more than 150 software (grouped in the categories (i) Architectural, Building Performance Energy Analysis and Simulation, (ii) Building Services, (iii) Construction Management, (iv) Data Server, (v) Development Tools, (vi) Facility Management, (vii) General Modelling, (viii) Geographic Information System, (ix) Model Viewer, (x) Other, and (xi), Structural) support import and/or export of IFC data.

IFC has become the open standard for BIM data since 1996 with its five releases IFC1.5.1, IFC2.0, IFC2x, IFC2x2, IFC2x3, and the new release IFC4. Each version is an improvement of the previous one, but the core remained unchanged to guarantee the compatibility with new applications and new formats. The new IFC4 is particularly essential to carry the geometry presented in this work. IFC4 expands geometry to support more complex shapes described using NURBS curves and surfaces.

On the other hand, the reuse of Revit information in ArchiCAD was affected by information loss. This has an impact also on the use of different mobile software, which can provide different results when a model is converted with different BIM software packages.

5. Conclusion

Mobile BIM applications are becoming very popular in the architecture, engineering and construction industry. HBIM generated from photogrammetric and laser scanning point clouds can be interactively visualized and inspected in the field (or in the construction site) to provide simplified access to project information. This can integrate printed projects boards and reports.

Mobile applications for specialists are intended as a practical solution able to move the exploitation of digital information from the office (desktop based solution) to the construction site (smartphones, tablets). Although PCs and monitors with a reasonable size remain fundamental for most technical work (e.g., project design), mobile devices are expected to become more popular for visual inspection and cloud-based collaboration.

This paper presented a real case study where a very detailed and accurate HBIM generated from photogrammetric and laser scanning point clouds was handled in mobile devices. The use of BIM applications like A360 and BIMx was necessary to preserve the information stored in the BIM database. The integration of cloud-technology allowed a direct inspection of the latest project version with an improved collaboration between the different specialists involved in the project. Some interoperability issues were found when the same model is handled with various applications. As things stand at the present, full interoperability is not completely guaranteed during the conversion of the model (e.g., from Revit to ArchiCAD) also with the IFC format.
This caused an information loss for some complex objects modeled with advanced solutions able to preserve the complex shape revealed by dense point clouds. For this reason, the case of historic BIM that cannot rely on existing object libraries poses additional problems not only for issues related to the

better levels of detail in terms of geometry, but also for the information associated to the different constructive elements, that could be lost with different desktop and mobile applications.

Acknowledgments
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A SKETCH AND IMAGE-BASED 3D REPRESENTATION OF THE DERVENI BOARD GAME USING THE CHER-ISH SOFTWARE

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Περίληψη

Η παρούσα εργασία παρουσιάζει την ψηφιακή αποκατάσταση του επιτραπέζιου παιχνιδιού του Δερβενίου, το οποίο ανακαλύφθηκε το 1962 κοντά στη Θεσσαλονίκη, μαζι με πολυάριθμα κτερίσματα στον τάφο Β. Προτείνει μια μεθοδολογική προσέγγιση, η οποία ενσωματώνει την ανάλυση των υλικών αποδείξεων, την εξερεύνηση της βιογραφίας του αντικειμένου, καθώς και έρευνα για παρόμοια αντικείμενα, προτού προχωρήσει σε μοντελοποίηση με βάση το σκίτσο χρησιμοποιώντας το πρόσφατο λογισμικό CHER-ish και στη συνέχεια 3D ψηφιακή αποκατάσταση. Ταυτόχρονα, η μελέτη αυτή εξετάζει τις δυνατότητες του συνδυασμού 3D απεικόνισης με βάση το σκίτσο και την εικόνα, πέραν των εφαρμογών αρχιτεκτονικής και διαχείρισης χώρου, με σκοπό την αξιολόγηση του συστήματος για την ψηφιακή αποκατάσταση κινητών μνημείων. Η προτεινόμενη μεθοδολογική προσέγγιση προσφέρει την ευκαιρία στους επαγγελματίες της πολιτιστικής κληρονομιάς χωρίς εμπειρία 3D μοντελοποίησης να συνεισφέρουν την πολύτιμη γνώση τους για την παραγωγή τεκμηριωμένων τρισδιάστατων εικονικών ανακατασκευών.

Abstract

This paper presents the virtual reconstruction of the Derveni board game, discovered in 1962 in Northern Greece along with numerous grave offerings of grave B. It proposes a methodological approach for virtual reconstruction, which incorporates analysis of the materials evidence, exploration of the object's biography, timeline and values analyses, as well as research on information for similar objects, before proceeding to sketch-based modelling using the recently released CHER-ish software and 3D modelling for virtual reconstruction. At the same time, this study examines the possibilities of combined sketch and image-based 3D representation beyond the architectural and site management applications already proposed, intending to evaluate the system for the virtual reconstruction of portable antiquities. The proposed methodological approach offers the opportunity to cultural heritage professionals without 3D modelling experience to contribute their valuable knowledge towards the generation of evidence-based 3D virtual reconstructions.

Λέξεις Κλειδιά/Keywords: CHER-ish, Derveni tombs, board game, illustrations, 3D, RTI, virtual reconstruction

1. Introduction

The Derveni cemetery, accidentally revealed in 1962 10 Km NW of Thessaloniki, Macedonia, is an archaeological site of great significance in the region of Northern Greece. The six cist- and pit- graves that were then excavated are dated to the end of the 4th century B.C. (Themelis & Touratsoglou 1997). They contained rich grave offerings; some of them considerably older than the burials. The deceased were members of the same influential family of Thessalian origin and the cluster of their graves belonged to the territory of ancient Lete, the city which is situated to the NW of the tombs. Lete was the most significant city of Mygdonia, the area extending from the Axios River to the Langada and Volvi lakes. The city was named after a local sanctuary dedicated to Leto and was strategically placed near a significant ancient road, the Derveni pass, which permits access from the Thermaic Gulf to the Macedonian hinterland.

The biggest and richest Derveni grave was grave B, with a male and a female burial. In addition to the elaborate relief bronze krater, it contained over one hundred objects in an admirable variety of materials: gold, silver, bronze, iron, clay, stone, and various organic materials. The Derveni board game was found during the cleaning of the floor of Tomb B. The surviving remains of the artefact are mainly glass and metal components, interpreted as pieces of an ancient kubeia board game, a family of board games played with counters and dice (Fig. 1).

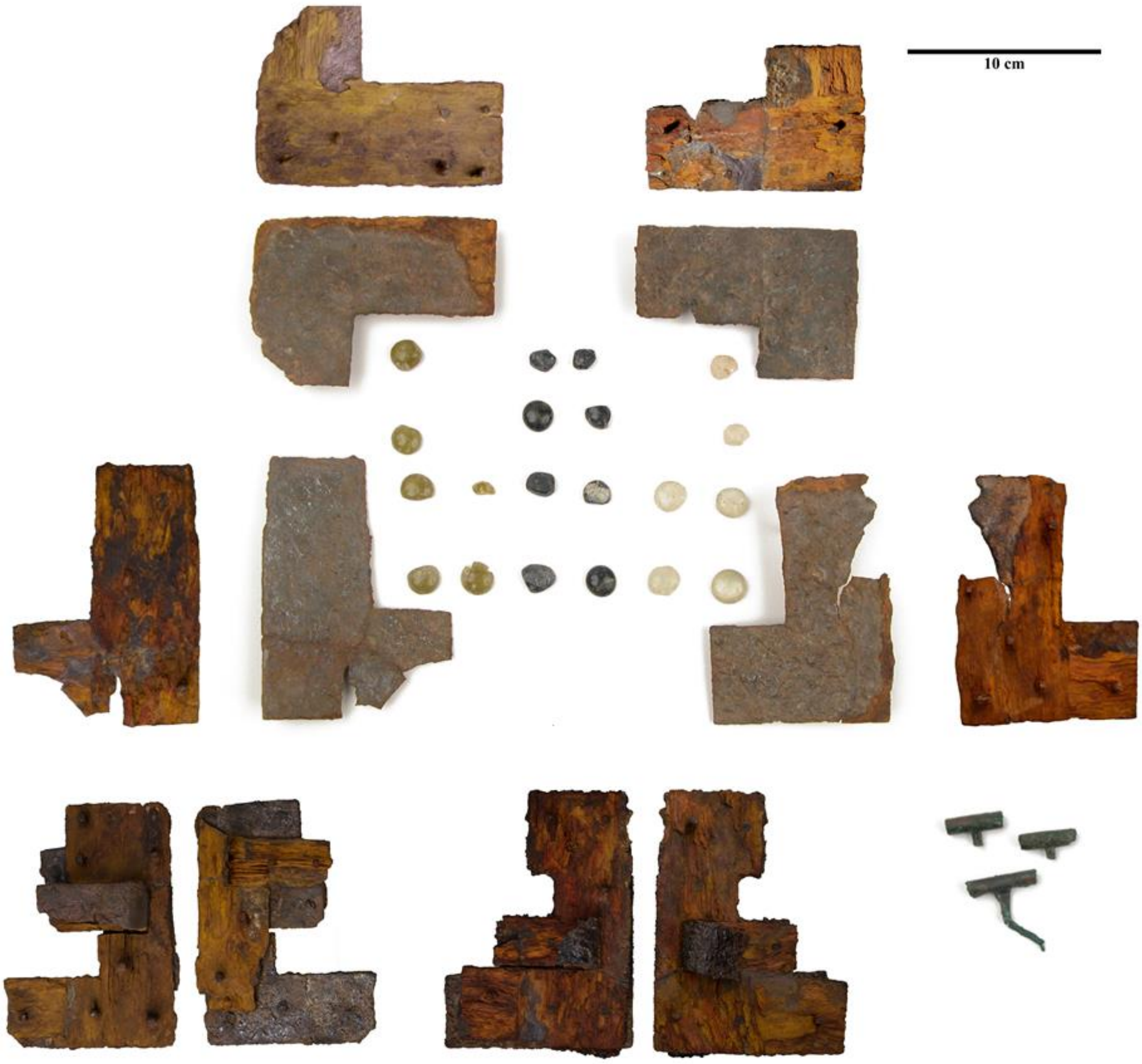

Figure 1 The Derveni board game fragments.

Recent research suggests that the board game belonged to a warrior, priest, and healer and was used as a pastime as well as part of the healing process (Ignatiadou 2016). The conceptual model of the original appearance of the find was that of two hinged wooden boards, with iron corner reinforcements (Ignatiadou 1999). Additionally, twenty-one complete glass pessoi or gaming pieces and four in fragmentary condition are associated with the board game. The translucency and the colour varies; translucent dark blue, translucent olive or transparent colourless with a slight greenish tinge. Thirty-two iron parts of plates of rectangular shape have been discovered, originally part of the board, with remnants of the wood panel in the downside, and four from the corners, which have undergone extensive corrosion and formed, in couples, a non-separable mass, due to wood collapse and metal corrosion. Other possible existing parts of the board assembly are the three bronze hinges.

2. Research goals

The artefact's conservation, interpretation and display raise interesting questions considering both material evidence and non-material aspects of the object. Problematic issues are the bad state of conservation of the remaining fragments, especially the extensive fragmentation of the metal parts of the board. Some fragments are simple, intended to support the outer or external sides of the wooden board, while others are complex couples of its iron assembly. Among the most interesting fragments are those from the corners of the board, which was fully supported from both sides. Furthermore, questions arise about the bronze hinges and their possible role. Moreover, the properties of glass gaming counters, such as colour and shape, their function in the game, and their likely attribution to three players, are considered an intriguing matter of discussion.

For the purposes of the present study visualizations of the Derveni board game, such as digital images, illustrations, Reflectance Transformation Images and renderings from virtual reconstruction scenarios are explored in the recently released Cultural Heritage - information for site history (CHER-ish) software (Rudakova *et al.* 2017). The CHER-ish is an open-source software developed at Yale University on 2017 available at https://vicrucann.github.io/cherish/. It aims at the generation of comprehensive 3D spaces based on expert knowledge and visual dataset.

Already presented case studies were focused on the representation of either historical or urban and archaeological structures in 3D by means of image manipulation and sketching, such as the Strawbery Hill historic house and the Dura-Europos site (Rudakova *et al.* 2017). Previous work has revealed the potential of sketch-based modelling for virtual reconstruction of incomplete objects (Bein *et al.* 2012). But processes such as filtering and interpretation, largely discussed in sketch-based modelling literature (Olsen *et al.* 2009), might be problematic in an archaeological context because shapes are usually incomplete with discontinuities. Also, browser-based 3D modelling approaches (Sandnes & Lianguzov 2017) are not applicable because a visual input is necessary so as to design the complex shapes of archaeological objects.

The aim of this project is to explore the available information for ancient games and their structural elements as well as material evidence and archival records for the Derveni Board game and integrate the available visualizations in an attempt to reach conclusions regarding its original shape and form. Apart from the integrity of the discovered fragments and the appropriate identification of their position and use, this study considers the diachronic presence of this type of games, its discovery in a burial full of luxurious grave offerings and other similar objects excavated in the region or elsewhere. An in-depth systematic analysis of the objects' biography, timeline and values analysis (Appelbaum, 2007) sheds light to the already stated issues and holds the balance between intervention, investigation, prevention and communication of the treatment.

Additionally, this project provides the opportunity to explore the possibilities of combined sketch and image-based 3D representation and documentation beyond the architectural and site management applications already proposed in the published literature. Via this study, we intend to evaluate the CHER-ish software for portable antiquities research and potentially propose a new methodology for virtual reconstructions.

3. Exploring the Derveni board game

3a Advanced Systematic Visual Analysis using RTI

Reflectance transformation imaging (RTI) is an imaging technique used as museum documentation, examination and finds analysis, useful for conservators, archaeologists, curators and finds' specialists. It is a group of technologies for surface characterization (Mudge *et al.* 2010), which includes Polynomial Texture Mapping (PTM) (Malzbender *et al.* 2001). The Derveni board game RTI leads to better understood and more advanced documentation of depositions and encrustations, physical damage characterization, decorative elements, surface features, manufacture or fabrication and previous treatment evidence. Characteristic examples are provided in Fig. 2.

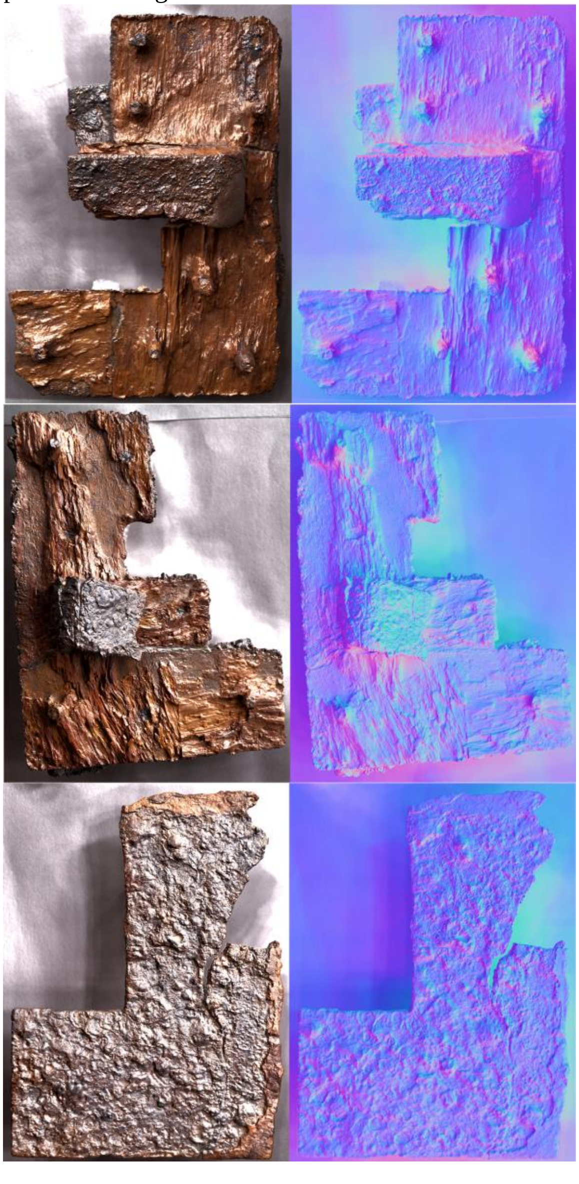

Figure 2 RTI visualizations of Derveni board game fragments in specular enhancement rendering mode and normal maps.

3b The artefact's biography

The wooden board was created from different pieces of wood, supported by iron plates, made of single pieces of wrought iron forged to form the rectangular shape. The connection between wood and iron was secured with nails. The three bronze hinges were made from three different parts each: a bronze foil in a cylindrical shape, and two projections in the middle of the cylinder's length. The glass gaming pieces were made by reheating into a kiln of small pieces of scrap glass without further manipulation, based on Lierke's experimental reproduction (Lierke 2001).

Due to the lack of surviving evidence, the alterations in the material state of the artefact relevant to its use cannot result in any conclusions. During its burial the wood degraded and collapsed, the iron corroded and in some cases formed an inseparable mass. The vast majority of iron nails broke, as well as the bronze hinges. The glass gaming pieces corroded and in some cases broke. The discovery of the artefact resulted in a sudden change of its environmental conditions, forcing further corrosion. Conservation treatment included cleaning, joining and consolidation operations, followed by study and interpretation. Nowadays, some of its fragments are exhibited and others stored.

3c Values analysis

The aesthetically appealing characteristics of the board game have diminished. The corroded and fragmented iron frame, as well as the remnants of the wood panel, allows no margin for aesthetic enhancement. Consequently, the restoration of aesthetic integrity can be considered neither feasible nor desirable. Also, the important research questions of the identification of the fragments of the board the positioning of the hinges and the function of the game, along with conservation ethics, demand the safeguarding of the material integrity and the protection of the historical truth, so that it can be re-examined in the future, without distracting modern additions.

On the other hand, the public should gain access to the object, because of its high educational value. For the object to be understandable by lay viewers in the context of museum visitation, an enhanced, less fragmentary appearance of it is necessary. Furthermore, the rarity of board games of that type, due to physicochemical or/and sociocultural factors, as well as its association to the Derveni cemetery, which is a well-known archaeological site, and in particular to Tomb B, where the impressive large krater was found, are additional reasons for the analysis and study from an archaeological research perspective. The treatment of the Derveni board game should be targeted to improve access to the object and simultaneously to protect its material integrity, because of its rarity and vulnerable nature.

4. Ancient games and their structural elements

While knucklebones were played by women and children, board games were the pastime of men, especially of the hero–warriors. According to ancient writers, the board games can be categorized in *petteia* and *kubeia*. The former group of games, such as *diagrammismos* or *grammai*, as defined by Hesychius, and *poleis*, according to Pollux, includes strategy games played with gaming pieces but without dice over a table or board, usually made of wood or clay. Plato mentioned *petteia* games and considered them science or at least activity that requires great skill. *Kubeia* games consist of lucky games that are played only with dice or competition games played with gaming pieces and dice on a table or board. One of the most popular board games was *pente grammai* ("five lines"), played with dice and gaming counters (Austin 1940, Schädler 2009). According to Avedon, the games are composed of 10 elements: purpose, results or pay-off, number of required players, roles of participants, rules governing action, abilities and skills required for action, physical setting and environmental requirements, required equipment, procedures for action and interaction patterns (Avedon 2010). Table 1 summarizes the available data about Greek games during pre-Roman times.

Examples of boards found are rather limited in comparison to that of bone dice and gaming pieces (Ignatiadou, forthcoming). A possible explanation could be the sketching of the pattern of the game on the ground, but the case of misinterpretation of board fragments should be considered, too. A variety of materials were used for the construction of gaming boards and tables, such as ceramic tiles and marble. The earlier examples of board games in Greece date back to the Bronze Age, mainly from Crete, where the magnificent Knossos gaming board was found. Also, in Cyprus, stone plaques with circular recesses were interpreted as boards. From the study of incised lines on ceramic tiles from the Roman times, found in the ancient agora of Thessaloniki, two different structures are discernible, which correspond to the game *diagramismos*. The game *poleis* is associated with clay gaming tables from Perachora, 7th-6th BC, a Laconian type roof tile with incised lines of rectangular shape from the Archaic and Classical periods of ancient Fagres, as well as a marble table from Abdera. A small clay board table with five parallel incised lines, 2+1+2, ending in circular depressions at the ends of each line from 7th-6th BC, found in Anagyrous, is decorated with female figurines, in the four corners. Another example of pente grammai game is the Copenhagen table, 6th BC, made of clay, with 4+1+4 lines. There are a large number of stone board tables with 5+1+5 lines, such as the deteriorated fragments of marble tables found in Stageira and Abdera.

Elements of Games	Peteia		Kybeia	
	Diagrammismos	Poleis	Kyvon anarriptein	Pente grammai
	noughts and crosses	chess	craps	backgammon
Purpose of the game	to place gaming pieces in specific formations	to encircle and neutralize the gaming pieces of the enemy	to achieve the highest sum of grades by rolling the dice	to arrive first at the central line
Number of participants	At least two			Two (or three?)
Rules governing action	Mostly unknown			
Abilities and skills required for action	Strategy/tactics		No special skills	
Required equipment	Gaming pieces on a board		Dice	Gaming pieces on a board with eleven parallel lines (5+1+5). Three dices
Procedure for action	To move gaming pieces on a board		To roll dice	To move gaming pieces on a board, following the lines and after rolling the dice
Interaction pattern	competitive nature, antagonist		no interaction between participants	competitive nature, antagonist

Table 1. The elements of ancient Greek board games

The structure of the gaming board with the incised lines can be found on a few Corinthian roof tiles from the area of Pydna, unfortunately in fragmentary condition. The game was played from the first half of the 4th BC, based on the archaeological evidence from Makrygialos lot 951 (Ignatiadou 2013).

The popular amphora by the Andokides Painter depicts Achilles and Ajax playing a dice game on a board (Boardman 1975). On an Etruscan mirror with the same scene, the two heroes hold the board in their knees and the *tabula lusoria* is shown in detail. A similar board was represented, in relief, hanging on the wall in the tomb of the reliefs at Cerveteri (Bonfante 1987).

Glass gaming pieces are plano-convex and roughly circular objects. They are often colourless, or light green, but they have also been found in blue, green, bluish green, olive, and amber. Unlike earlier counters found in Italy, which were decorated with dots or spirals, the examples found in Macedonia are undecorated. For games that involved multiple players, polychrome gaming pieces were a necessity. Gaming pieces formed sets in two or three colours (usually blue, colourless, and olive-green). The latter is rarer than the other two, and it was often replaced by a group of pebbles (Ignatiadou 2002). In Macedonia, the sets were accompanied by three to five bone-dice with rounded edges and corners, yet dice were not found in Derveni; they probably deteriorated completely or were damaged during excavation.

5. Virtual reconstruction

Values analysis, discussed in section 2.c, manifests the controversial conservation needs of the object and leads to the accessibility versus integrity a dilemma. Digital technology provides alternative approaches to such dilemmas, reaching a compromise between material fetishism and excessive aesthetic restoration approaches. The present paper examines other methods of interpretation outside the object by means of virtual reconstruction, providing an improved understanding, securing accessibility and compliance with conservation ethics.

5a Sketch-based modelling

The drawings representing their association were arranged in 3D space using canvases, which represent planes. These visuals were also bookmarked, so as to enhance the accessibility during the sketching process. Features which appear in the visuals were sketched, either using freehand digital drawing or straight lines. Introducing changes interchangeable in the transparency of the visuals made it possible to combine in the sketch information derived from different images. The strokes were separated in more canvasses for a more detailed representation of shape and form (Fig. 3).

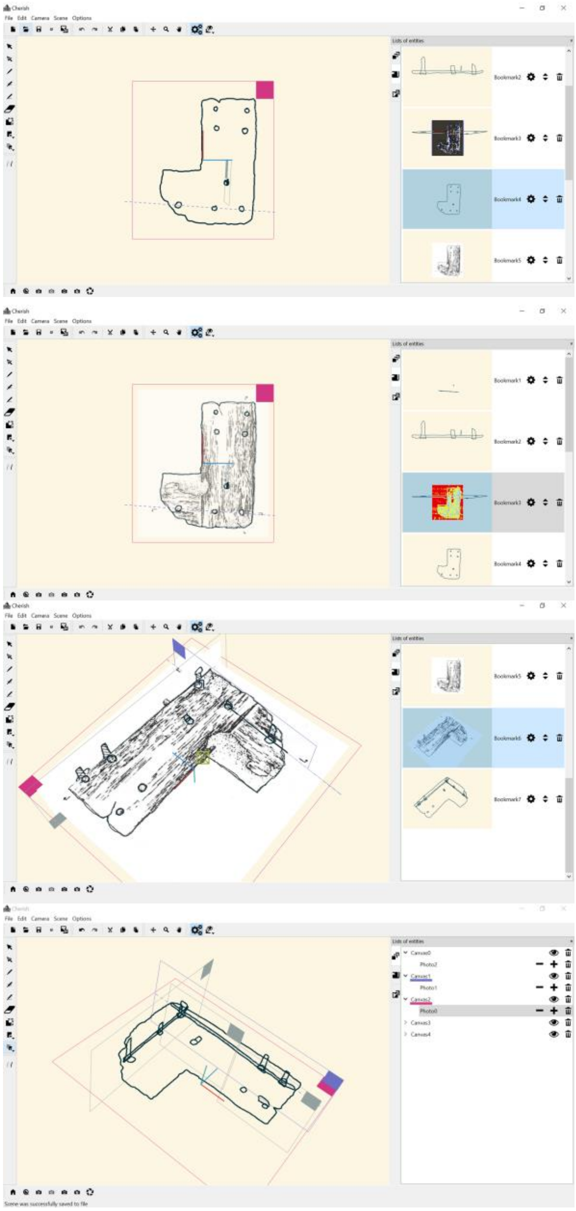

Figure 3. CHER-ish screenshots during the development of the project.

In an attempt to include more details, RTI renderings were used as a basis for sketch-based modelling. Details added were the modern additions, such as restored areas, material loss, cracks, and also remnants of wood. Also, joining of different pieces of iron was revealed via RTI and added in the 3D sketch (Fig. 4). So, starting from a simple 3D sketch, which represents the shape, we finally had an informative 3D visualization of features relevant to manufacture evidence, decay, and previous restoration.

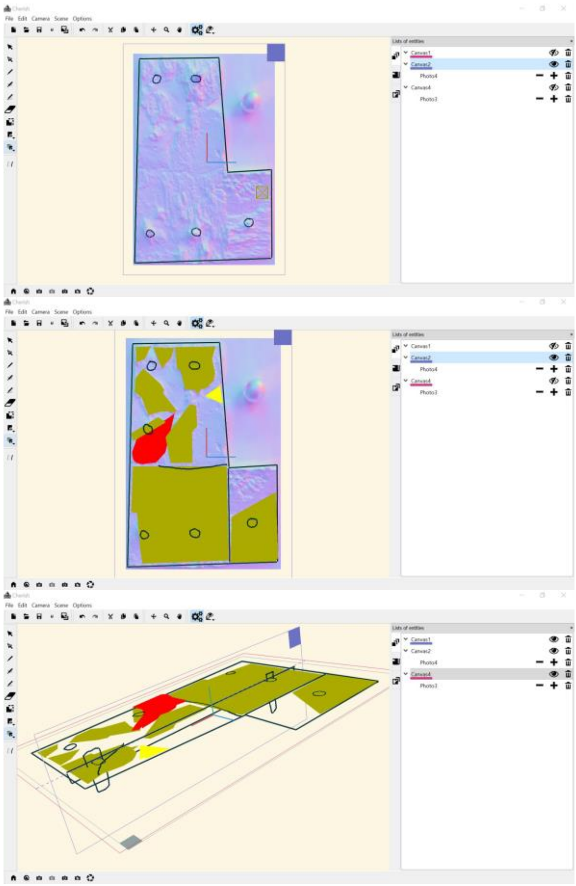

Figure 4. CHER-ish screenshots during the development of the project.

5b 3D modelling

The individual 3D sketches completed in CHER-ish were exported in 3DS. The 3D sketch model includes the 2D visuals used for the drawing, assisting in keeping track of the positioning and shape of features. Each component of the model appears as a different geometry, which can be isolated, selected, hidden during the reconstruction process (Fig. 5). This presents similarities to the FOCUS (Formalised Object Construction and Use Sequence) approach (Caple 2000). This correlation of the virtual de-construction of the artefact to its low-level entities, during the development of the project, provides a detailed evidenced based description as well as advanced opportunities for interpretation. The 3D sketch models include all the information for the necessary reconstruction of the basic shape and form of the fragments. Remnants of broken and corroded iron nails were elevated to the final length. Full-length nails were respectively added to the corner fragments, based on the circular marks of missing/broken nails, still evident on the iron surfaces. The thickness of the wooden board was concluded by the height of the nails, which coincides with the height of the inserted curved iron element.

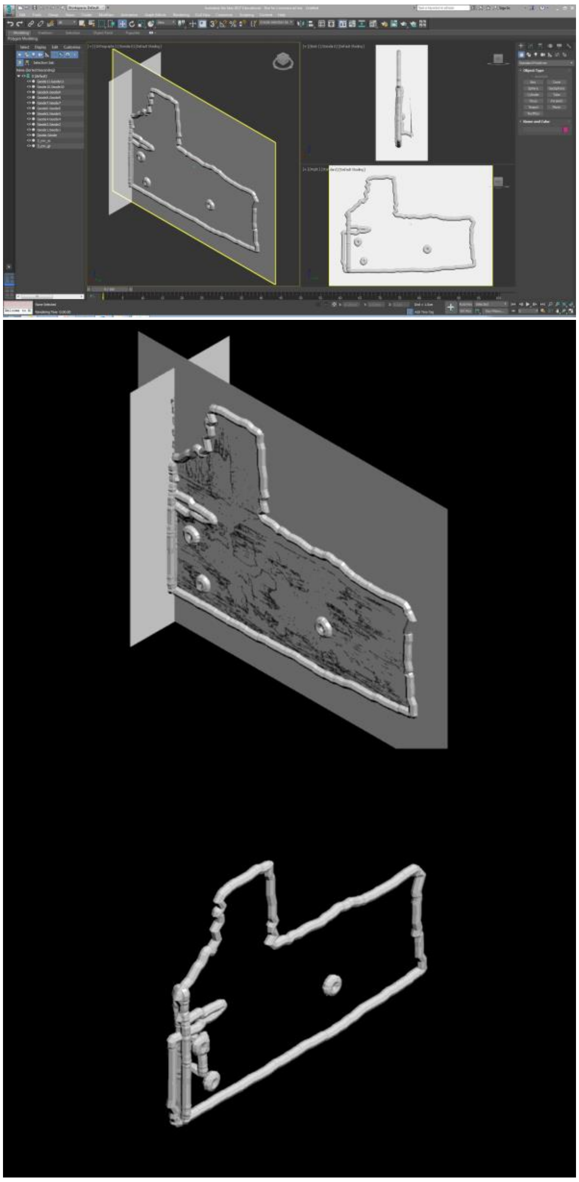

Figure 5. 3DS Max screenshot and renderings after importing the 3D sketch model.

Positioning the remaining board fragments in different positions leads to a series of possible virtual reconstructions.

- The double corner fragments were placed on the outer corners of the wooden board, while the single ones covered the inner corners (Fig. 6 above).
- The double corner fragments were placed on the inner corners of the wooden board, while the single ones covered the outer corners (Fig. 6 middle).
- The curved iron parts, currently inserted in the double fragments were placed vertically, in an attempt to visualize their function as folding legs (Fig. 6 below)

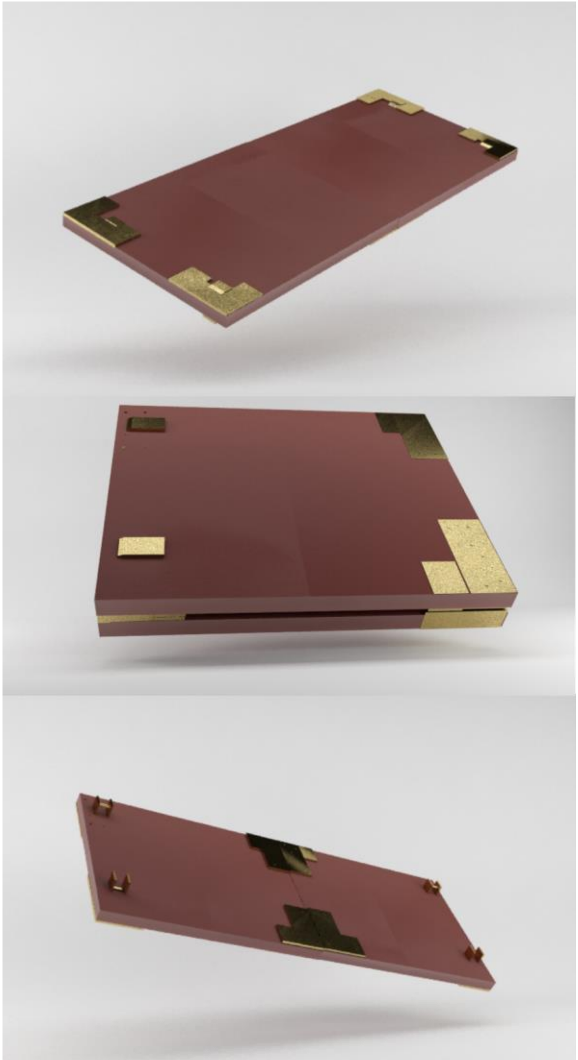

Figure 6. Virtual reconstruction scenarios.

6. Concluding remarks

This paper proposed a methodological approach for virtual reconstruction, which incorporates analysis of materials evidence, exploration of the object's biography, timeline and values analyses, as well as research on information for similar objects, before proceeding to sketch-based modelling and 3D modelling for virtual reconstruction.

For the development of the Derveni board game CHER-ish case study, the dataset consisted of drawings, 2D images, RTI snapshots and virtual reconstruction renderings. The software was used as an aid for virtual reconstruction as well as an integration tool, for the addition of details. Considering that computational photography tools are increasingly being used for recording and documentation, a large number of visuals is generated. Additionally, 3D reconstruction requires modelling skills and expertise. So CHER-ish can be used by archaeologists, historians, museum experts without previous experience making use of the long tradition of archaeological drawing as well as the user-friendly interface for the generation of simple but informative 3D sketches.

The proposed pipeline is advantageous because it incorporates different types of visualizations in the virtual reconstruction process. The sketches include knowledge about the artefacts and their interpretation and explain the 3D reconstruction hypothesis without the need of modelling skills. More stroke sizes and colour will make the resulting 3D sketches much more informative and easier to discern.

Acknowledgements
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3D RECONSTRUCTION OF CHURCH WALLS (ST. MARTIN, PONIKVA, SLOVENIA)

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Περίληψη

Αυτό το άρθρο παρουσιάζει τα προκαταρκτικά αποτελέσματα ενός συνεχιζόμενου έργου και τις προσπάθειές μας να συνδυάσουμε σύγχρονες και αποδοτικές τεχνολογίες για κλασσικές αρχαιολογικές πρακτικές. Η αρχαιολογική έρευνα κατά τη διάρκεια κατασκευών γύρω από την εκκλησία του Αγίου Μαρτίνου στη Ponikva της Σλοβενίας συμπλήρωσε την εικόνα γύρω γύρω από την εκκλησία με τον πύργο άμυνας.

Κατά τη διάρκεια των ανασκαφών μας, εντοπίστηκαν αρκετοί νέοι τοίχοι, τους οποίους μπορέσαμε να συνδυάσουμε με τους υφιστάμενους τοίχους. Προκειμένου να κατανοήσουμε καλύτερα τις συνδέσεις μεταξύ πρόσφατα ανακαινισμένων και ήδη ανακατασκευασμένων τειχών, αποφασίσαμε να τα οπτικοποιήσουμε σε ένα 3Δ περιβάλλον. Αυτό επιτεύχθηκε χρησιμοποιώντας φωτογραμμετρία για τη δημιουργία τρισδιάστατων μοντέλων και ορθοφωτογραφιών από αυτόνομα συστήματα πλοήγησης και επίγειες εικόνες που είχαν γεωαναφερθεί με GPS και μετρήσεις από ολοκληρωμένους γεωδαιτικούς σταθμούς. Στο μέλλον σκοπεύουμε να συμπληρώσουμε την τρέχουσα ανοικοδόμησή, ενσωματώνοντας τους τάφους που έχουν εντοπιστεί και προβάλλοντας διάφορες φάσεις και αλλαγές σε αντικείμενα κατά τη διάρκεια διαφορετικών περιόδων. Το αποτέλεσμα θα είναι ένα 3Δ περιβάλλον του τόπου ανασκαφής με βάση τη χρονολόγηση.

Ένας στόχος της μεθοδολογίας μας ήταν να αξιολογήσουμε την ακρίβεια των γεωναφερμένων μοντέλων. Αυτό έχει επιτευχθεί με τη σύγκριση δεδομένων που λαμβάνονται από τα γεωαναφερμένα με GPS μοντέλα σε σχέση με τα μοντέλα που έχουν προκύψει από τον γεωδαιτικό σταθμό. Σε περίπτωση αμελητέου σφάλματος ακρίβειας, η απόκτηση δεδομένων απευθείας από αυτόνομα συστήματα πλοήγησης είναι πολύ ταχύτερη και πιο εύκολη.

Abstract

This article presents preliminary results of an ongoing project and our efforts to combine modern cost-efficient technologies with classical archaeological practices. Archaeological research during construction around the church of St. Martin in Ponikva, Slovenia supplemented the ground plan of the anti-Turkish camp wall around the church with its defense tower.

During our excavations, we have found several new walls, which we could combine with, previously discovered reconstructed walls. In order to better understand the connections between newly discovered and already reconstructed walls, we decided to visualize them in a 3D environment. We did this by utilizing photogrammetry in creating 3D models and orthophotos from drone and terrestrial images that were georeferenced with drone GPS and total station measurements. In the future work we intend to supplement our current reconstruction by incorporating discovered graves in our interpretation of the site and visualizing different phases and changes made to objects during different periods. The result will be multiple 3D models of excavation site based on chronology.

The other aim of our methodology was to evaluate the accuracy of georeferenced models. This would be accomplished by comparing data obtained from models referenced with GPS system in our drone and models referenced with total station and the third option of measuring with total station directly on site and not on models. In the case of negligible accuracy error, obtaining data directly from models referenced with drone GPS would be much faster, more efficient and easier.

Λέξεις Κλειδιά/Keywords:, 3D, St. Martin in Ponikva, cost-efficient technologies

1. Geographical and historical description of Ponikva

1a Geographical and geological description of environmental areas of research

The archaeological site is located in Ponikva, Slovenia, in the eastern part of the settlement, east of the brook Slomščica, under the Resevno hills. It lies within the area of a protected archaeological site, which is registered in the Register of Immovable Cultural Heritage as Ponikva - the Church of St. Martina (EŠD 3276).

The very name of Ponikva indicates the karst character of the province. The name of Ponikva comes from the German form of Ponigl and signifies the characteristic landscape, full of depression and intrusions in which the water suddenly disappears. In the area of Ponikve there are many small sinkhole's, ponds, karstic springs, dry valleys and the smaller karst caves. As a result of the action of water flows and the geological composition of the territory, the ridge-valley structural relief prevails (Rman 2010).

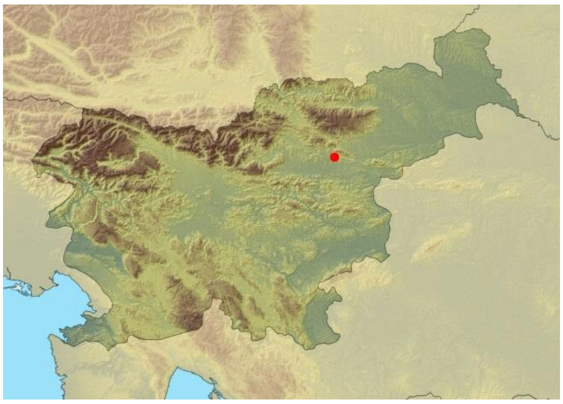

Figure 1 Location of Ponikva in Slovenia (www.geopedia.si).

1b Historical description of the environment

The area of Ponikva was already inhabited in the early Stone Age – Neolithic, which is confirmed by the stone axes discovered in near Slatina.

Several archaeological remains from Roman times were found, such as a Roman cemetery with nine sarcophagus as well as a stone pavement side road that led across Ponikva as a connection to the main Roman road Celeia - Poetovio. At the place of a castle, there was a quadrangle, a smaller fort where a small section of the Roman legion was housed.

Historical sources also testify about the early formation of the parish in Ponikva. The fact that the parish was established in the 11th century leads us to conclusion that the Romanesque church stood here during this time. It was dedicated to St. Martin, the worship of which came under Frankish influence in our region and was the most intense in the 7th to 10th centuries.

Ponikva is first mentioned in written sources in 1203 when the document of Duke Leopold VI Babenberg was issued. According to the historical archives of Celje, the first court in Ponikva dates back to the 12th century.

Christianization of this area took place from the Episcopal center in Aquileia. Church of St. Martin is mentioned for the first time in 1236 (Höfler 2016). The present building was built in the years 1732-1737. The Turks repeatedly robbed and murdered people in Slovenia, especially in the 15th century. They also did not spare the Styrian territory and consequently Ponikva. The Turkish invasions affected the area three times (in the year 1473, 1493 and 1529). Based on the travelogue of Paolo Santonini through Carinthia, Carniola and Styria from the 15th century, the villagers fortified the cemetery next to a church with a ditch, enclosed by a defensive wall with bastions (Baš, 1951). Four corner towers belonged to the camp wall (Curk 1992). The last one was destroyed in 1850. Along with the last, Kaplan's tower, the cemetery wall was partially removed (Stopar 1990).

1c History of research

In 2012, the archeological company Arhej d.o.o. at the arrangement of village core and drainage for the church of St. Martin on Ponikva carried out archaeological excavations.

The total investigated area included 765.1 m2 and additional 317.67 m2 were studied with geophysical methods around and inside the church.

The main part of the events in the researched area can be placed in the time of the late Middle Ages and the beginning of the new age. The stratigraphic sequence and historical sources also confirmed the phases before and after this period. As part of archaeological research in the regulation of the village core, the oldest documented phase was discovered by geophysical research inside the church. The results showed the structures that could be attached to the ground plan of the Pre-Romanesque church.

In the summer of 2017, the archeological company PJP d.o.o. carried out archaeological research in the area of the arrangement of the road to the parish and the footpaths from the parking lot to the church in Ponikva. The research was supplemented by the ground plan of the anti-Turkish camp wall around the church.

Figure 2. Fieldwork in summer of 2017 (Tušek 2018).

After the top layer was removed, a clay layer was discovered in which the highest skeletal graves and pits were dug in. The pits were part of the building stage for the reconstruction of the church during the Baroque period.

Figure 3. Graves from the 18th century (Tušek 2018).

2. Defence system against the Ottomans in Slovenia

Due to Turkish invasion that started around 1400 and ended in the first half of the 16th century, many forts, castles and churches like Ponikva church were built in Slovenia in the 15th and 16th century. By the end of the 15th century, a systematically distributed network of 350 to 400 "forts" was created. These forts had different shapes: from simply fortified subterranean caves and simple and complex walls with towers and lifting bridges to true "military" fortresses, built through whole valleys with prison walls, which prevented the passage of the Ottomans.

Forts against Ottomans have become the center of peasant life. Farmers kept their valuables in special granaries. Trades were made inside the walls and many sparks of peasant revolts were sprinkled in them. Authorities become dissatisfied and in 1515 order was issued that all the fortifications should be inspected and inadequately removed. Most of the fortifications disappeared in the 18th and 19th century.

There is a striking similarity between forts in Slovenia and "fortified churches" in Transylvania, which began to emerge a century before due to the Tatar invasion. The defense was organized similarly: they had a village manager, a system of granaries for individual families and the fort became the center of life. In addition, the fortified churches ("Wehrkirchen") in Styria and in the part of the Lower Austria and on the border of Slovenia with Croatia and Hungary are similar. The difference is that these fortifications were made for the defense of churches, while forts were designed to defend people (Gorenc 2006).

Figure 4. Reconstruction of a fortified church in Krtina pri Domžalah, Slovenia (Gorenc 2006).

In the second half of the 15th century, the rural fortresses began to be formed according to all the rules of the fortified architecture with fortified entrances, lifting bridges, defense trenches, multi-storey walls, covered corridors, defense and observation towers, towers for refuge, specially designed firearms for various types of weapons, etc. Large fortifications sometimes encircled the entire settlements. This enabled the continued protection of property and, if necessary, a shelter for humans and livestock.

The special sections of the forts were towers. They were built to defend against the attackers, who could hide just below the wall and who would like to undermine or climb the walls. They held the best-armed defenders. Sometimes the old round ossuaries were turned into towers, but most often new ones were built. The other important component of the forts were granaries, made of stone or wood. The buildings were built inside the camp walls and divided into small rooms in which each family had its own assets in large trunks, sometimes even barrels. They contained the most important assets: grain, dried meat, clothes, and sometimes also documents.

Ponikva experienced three invasions of the Ottomans. The first was in 1473, the second in 1492, and the third in 1529. It is known that in 1491 the cemetery and the church were fortified with a ditch and a stone wall with a serrated overhead or bastion. At that time, natural disasters (floods, hunger and locusts) and diseases (plague and red grief) also threatened Ponikva. At the end of the 18th century, two fires hit the village, which destroyed the old parish. Only two houses remained undamaged.

Figure 5. Reconstruction of a fortified church in Tabor nad Cerovim pri Grosuplju, Slovenia (Gorenc 2006).

3. Methodology

The drone DJI Phantom 4 Pro and Nikon D40 camera were used for capturing the data. Our excavation was large and complex. So far, we have found 330 graves and several different walls that were built in different stages. Therefore, we decided to use the drone for better and easier transparency and for clearer height capturing. We selected photogrammetry for data capture technique and Agisoft PhotoScan for processing. Photogrammetry is a process of capturing successive overlapping photographs. The final result is a 3D model. We used 3D models for interpretation of our fieldwork.

In the next phase, we decided to use 3D models to capture the same data, as it would otherwise be obtained on the ground with the total station. The procedure was as follows: First, we placed markers around the explored location and measured them with the total station. These coordinates were then inserted into the Agisoft model. We discovered, that drone GPS alone is not sufficient for accurate data (the error is approximately 20 cm). Therefore, we still referenced the models on the basis of markers. Then we took photos of the specified area with drone, using the photogrammetry technique. These images were inserted into Agisoft PhotoScan and a 3D model was made from them. Two of our 3D models are represented in figure 10 and 9. We were doing measurements on these and other similar models. Based on the model we made orthophotos, which we used on the field for better visualization. In Agisoft, we used the Vector Line tool on the model to capture data, which we would otherwise measure on the field with total station. These data (shapes in Agisoft) were inserted into ACAD and combined with data from the total station. We have found that the results are very similar and precise enough for future use, so that the procedure could replace the current one (measuring with the total station on field). We would still use the station to georeference the models in the environment. The down side of such a procedure is that it would be necessary to have enough equipment (computer) on the field for real-time processing of 3D models.

The next stage of our work was the reconstruction of excavated walls, yet again to better understand the chronology of excavated walls and graves. We used Google Sketchup in which we imported our ACAD plans that were obtained through field measurements or on-model measurements (described above). We used Google Sketchup because it is a very simple tool for providing on-field reconstructions. Then, the walls were reconstructed to the desired height with the Push/pull function. Because of this, we discovered that there was many overlapping walls and that those could not function in the same time period. We figured that we do not need detailed reconstructions directly on the field for that kind of results. Because this was intended just as a help to decide how are we going to proceed with excavations. Detailed reconstructions will be made at the completion of the excavations. We discovered that there was a huge rebuilding and additional building of the walls in this area. Also, many graves were buried between and under the walls, which made the understanding of the situation even more difficult. Nevertheless, we managed to figure out, where the line of particular walls was running. One of those reconstructions are represented in figure 7 and 8. Figure 7 and 8 are representing just one stage of many trial reconstructions with which we tried to figure out the positions of walls and how to continue excavating. They are highlighted in blue in Google SketchUp. Our excavation is not over yet, so we do not have a chronological course or usage for the rest of the walls. We linked all our plans to the plans of previous excavations. Thus, with the reconstruction, the whole area could be connected. Detailed reconstructions will be made when we finish the excavations.

We found that the methods of data capture and processing that were used in this field proved to be very successful and useful. At some levels, there are some shortcomings but they could be improved over time.

4. Research results

The archaeological research in 2017 took place between the church of St. Martin and the parish, which stands on the south side of it. On the western, northern and eastern sides, the walls were already partly reconstructed in 2012. On today's walking surfaces, the walls of the fort are indicated by stone paving and at the places where it was possible, the entire width of the wall, about 1 meter high was reconstructed. The church stands on an exposed hill east of the village. Today's church is Baroque, built in the 1st half of the 18th century. At the turn of the 18th and 19th century, the parish was erected at the site slightly shifted from its original location.

Figure 6. Aerial view of the Church of St. Martin in Ponikva (Umek 2018).

Ponikva experienced three invasions of the Turks. The first was in the year 1473, the second in 1492, and the third in 1529. It is known that in 1491 the cemetery and the church were fortified with a ditch and a stone wall with a serrated overhead or bastion. The wall consisted of sandstone of 5 to 45 cm and 15 to 25 cm thick cutters, bound with white and pale yellow mortar. The thickness of the wall is 1 m. Two towers were discovered - one in the northeast and one on the southwest side. Perhaps the tower was also located on the south-eastern side.

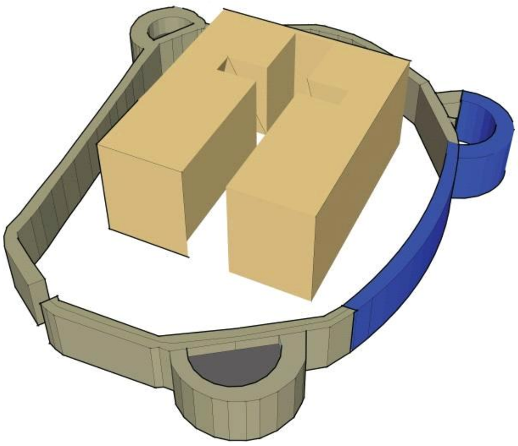

Figure 7. First defence wall (Umek 2018).

Finally, the third invasion of the Turks to Ponikva was in 1529. It is likely that a larger wall already surrounded the church. It may have been during this time that the church also increased, as there may have been a Gothic phase of the church, which has not been proven yet. The eastern and northern parts of the old wall were additionally fortified, and the wall was rebuilt at the north-eastern tower. On the eastern side walls were lower down the slope. Due to the construction of the parish, the course of the wall on the south side is unknown. Based on the bones discovered, the northeast tower was turned into an ossuary. The southwest tower was still in use at this stage.

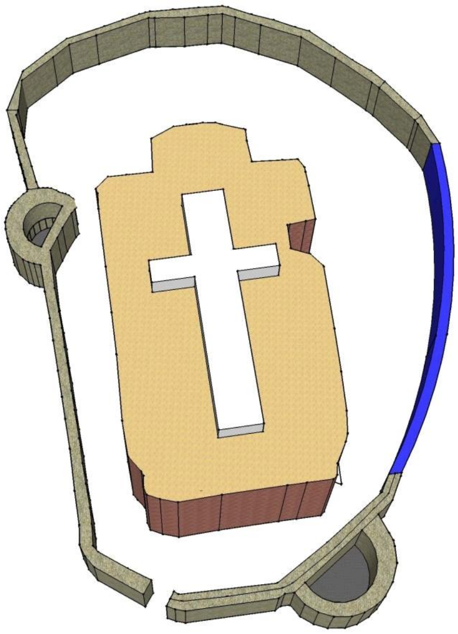

Figure 8. Second defence wall (Umek 2018).

After the end of the Turk invasions, the walls were probably abandoned. The forts against Turks have become the center of peasant life. Farmers kept their valuables in special granaries, trades were made inside the walls and many sparks of peasant revolts were sprinkled in them. That is why the authorities have become dissatisfied. In 1515, there was a demand that all the fortifications should be inspected and inadequately removed, and most of the fortification disappeared in the 18th and 19th century. The last tower was destroyed in 1850. Along with the last, Chaplain's tower, the cemetery wall was also partially removed.

Figure 9. Top view of a 3D model of the whole area (Umek 2018).

Natural disaster (floods, hunger and locusts) and diseases (plague and red grief) threatened Ponikva. At the end of the 18th century, two fires hit the village, which destroyed the old parish. Only two houses remained undamaged. Today's church is Baroque, built in the 1st half of the 18th century. At the turn of the 18th and 19th centuries, the parish was erected at the site of the old one, but slightly shifted from its original location. The only proof of the location of the old parish is a sewage socket, which was found north of today's parish.

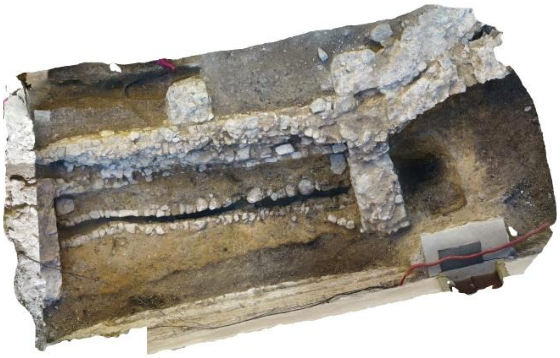

Figure 10. Top view of a 3D model of sewage socket (Umek 2018).

5. Conclusion

Our excavation was large and complex. We found 323 graves and several different walls, which were built in different stages. The research is not over yet, so the final result is yet to come. It is clear though, that the church of St. Martin in Ponikva with its defense walls played an important role in lives of people in 15th and 16th century. Our workflow and methodology turned out to be a good choice for this excavation. Using orthophotos made from 3D models turned out to be very useful directly on the field. You can get a top view of a complex site that you cannot get any other way. We were using this orthophotos directly on our tablets or phones to make notes or drawings on them or anything else what we found useful at the time. Also an excellent thing about it is that every orthophoto is already georeferenced so you can do all measurements directly on the field on tablets or computer. No need for those long meter tapes anymore. Also no need for obtaining other data with total station. Therefore, in this case our method speeded up the process of on-site measuring, note making and getting ACAD drawings directly on site. This means that you do not have that much work with ACAD in the office. Of course if you have orthophotos and models referenced with total station. Drones GPS is not accurate enough for precise measurements. Next thing is on-site reconstruction. We have used Google SketchUp because we did not need high quality models with textures directly on the field. We have shown two reconstructions in figure 7 and 8. We did them just to see which walls intersect one another. It gave us a different sight on how the walls were made. Although it is an interesting approach, we did not find it significant plus side that we found in 3D models, orthophotos and drones.

In the beginning, our new workflow was a little slow or slower than a previous established workflow or other methods. We had to figure out when it is useful to use drones, make 3D models, orthophotos, measuring on tablets (total station just for markers) etc., and when to use a standard camera, ladder, total station etc. In many situations new approaches are faster and easier but you have to know when and how to use them. Real time processing was the biggest challenge to overcome because it was not always possible to have computers, internet and electricity on the field.

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Session 5

Modern technologies for Cultural Heritage representation and promotion

FIRST YEAR UPDATE ON IMARECULTURE PROJECT TECHNOLOGICAL PROGRESS

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Περίληψη

Το ερευνητικό πρόγραμμα iMARECULTURE επικεντρώνεται στην αύξηση της ευαισθητοποίησης των ευρωπαίων πολιτών ως προς την ευρωπαϊκή ταυτότητα και πως αυτή διαμορφώθηκε μέσω των πολιτισμικών αλληλεπιδράσεων και του θαλάσσιου εμπορίου στη Μεσόγειο Θάλασσα. Το ερευνητικό πρόγραμμα αποσκοπεί στο να κάνει προσιτή στο ευρύ κοινό την εγγενώς απρόσιτη βυθισμένη πολιτιστική κληρονομιά, χρησιμοποιώντας σύγχρονές τεχνολογίες εικονικής και επαυξημένης πραγματικότητας. Το πρόγραμμα βασίζεται στην επαναχρησιμοποίηση υφιστάμενων τρισδιάστατων δεδομένων αρχαιολογικών χώρων για την δημιουργία εικονικών επισκέψεων, ενώ ταυτόχρονα προσφέρει υποβρύχιες εφαρμογές επαυξημένης πραγματικότητας για να ενισχύσει την εμπειρία των δυτών-επισκεπτών σε βυθισμένους επισκέψιμους αρχαιολογικούς χώρους. Εκπαιδευτικά παιχνίδια αναπτύσσονται για να προσελκύσουν επισκέπτες στα μουσεία ενάλιας αρχαιολογίας, προσφέροντας βασικές γνώσεις και αυξάνοντας το ενδιαφέρον των πιθανών επισκεπτών, πριν και μετά την επίσκεψη στο χώρο του μουσείου. Και τα δύο παιχνίδια θα πραγματοποιούνται μέσω κοινωνικών μέσων δικτύωσης, προκειμένου να διευκολυνθεί η ανταλλαγή πληροφοριών μεταξύ των χρηστών. Παράλληλα το πρόγραμμα διερευνά τα πνευματικά και ηθικά δικαιώματα, σε μια προσπάθεια καταγραφής των προβλημάτων και κωλυμάτων για μελλοντική αναφορά από παρόμοια έργα που σχετίζονται με πολιτιστική κληρονομιά.

Abstract

The project iMARECULTURE is focusing in raising awareness on European identity and how it was formulated through the maritime commerce, cultural interaction and exchange in Mediterranean Sea. The projects aim in bringing inherently unreachable underwater cultural heritage within digital reach of the wide public using virtual reality visits and immersive technologies. Apart from reusing existing 3D data of underwater shipwrecks and sites, to provide a personalized dry visit to a museum visitor or underwear augmented reality to the diver, it also emphasizes on developing pre- and after- encounter of the digital or physical museum visitor. These are implemented through two serious games like a sailing game and a shipwreck excavation game. Both games are realized thought social media, in order to facilitate information exchange among users. The project supports dry visits providing immersive experience through VR Cave and 3D info kiosks on museums or through the web. Additionally, aims to significantly enhance the experience of the diver, visitor or scholar, using underwater augmented reality in a tablet and an underwater housing. At the same time, the programme aims in creating a road map of intellectual property rights, ethical rights and licensing on cultural heritage dissemination and sustainability.

Λέξεις Κλειδιά/Keywords: Underwater · Archaeological sites · Shipwrecks · Maritime · Virtual museums · Serious games · Immersive · Holography · European identity

1. Introduction

The area of Virtual Museums, Virtual Guides and Virtual Reconstruction of Cultural Heritage, has a number of past and active projects of this scope (e.g. V-MUST, F-MU.S.EU.M., VENUS, MINERVA, MINERVA PLUS, MINERVA EC, THE MICHAEL PLUS, ATHENA, ATHENA PLUS, ARCHEOGUIDE, 3DMURALE, ViMM, GIFT etc.). However, these projects do not address the real challenge of an Underwater Virtual Museum. In addition, projects related to underwater cultural heritage and environments are not engaged with the challenge of Virtual Museums and Immersive Technologies. These projects (e.g. SASMAP, WRECKPROTECT, ARROWS, STACHEM, 3D-UNDERWORLD, NOPTILUS, CURE) are focusing on the development of tools and techniques to survey, assess, stabilize, monitor and preserve underwater archaeological sites using robot systems and scanners. It must be noted that most of these projects are not dealing with dissemination and wider public awareness of underwater cultural heritage. Most of the oldest underwater assets exist in the Mediterranean Sea are at risk due to the marine environment, trawlers, looting and wood degrading marine borers. Hence, recording and promoting CH is most important in the Mediterranean Sea than any other place.

The scope of the current paper is to inform about progress and research work that was completed and achieved, during the first year of the iMARECULTURE project. The scope of the whole project will not be addressed here in detail, as it has be done already in Skarlatos *et al.*, (2016)

1a Approach

Submitted in the call 'Virtual museums and social platform on European digital heritage, memory, identity and cultural interaction' (CULT-COOP-08-2016), the project investigates new ways to personalize museum visits to a digital of physical visitor, while support social cohesion and European identity. Virtual museums are particularly strong in visualizing CH that it is either intangible, does not exist anymore, it is partially destroyed, or it is remotely located. Ancient maritime commerce is a perfect example of civilizations' interaction and cultural exchange, but unfortunately not easily exhibited to the wider public. Ships, shipwreck sites and underwater sites in general, are far from public's reach and understanding. Enabling immersive technologies to allow for content enhanced dry visits of visitors on such sites, it will inevitably raise public's awareness and stir further interest about maritime culture.

The goal is to bring shipwreck sites to the reach of the wider public, so that they can have a personalized and interactive dry visit using VR googles from the comfort of their house. Museum visits could be further enhanced, using immersive technologies, such as VR caves and holographic screens. Moreover, the project will enhance the underwater experience of diver visitors, in submerged archaeological sites, that support such visits. Especially designed underwater tablets using Augmented Reality (AR) will superimpose information about specific finds and architectural designs on the screen of a specially designed underwater tablet. The information will be provided in real time, and on user's demand, to avoid overloading the diver.All the knowledge acquired through this project will lead to the creation of serious games in platforms (Anderson et. al., 2010, Mortara *et al.*, 2014); in order to extend any visit, pre- and after- the visit serious games and storytelling, encourage and surrounds the physical visit.

1b Underwater Sites

Three sites have been carefully selected for project's implementation, based on their ability to support the context of each action, as well as their data availability, so that no assets were to be allocated on data acquisition. The sites are the Mazotos shipwreck in Cyprus (Demesticha 2011), Xlendi shipwreck in Malta (Drap *et al.*, 2015; Azzopardi, 2013) and Baia underwater archeological park in Italy (Skarlatos *et al.*, 2016) all shown in Fig.1.

(a) (b) (c)

Figure 1: (a) The main concentration of Mazotos shipwreck site (photo: MARELab, University of Cyprus), (b) Amphorae laying on the seabed at the Xlendi wreck (Photo: The University of Malta/ COMEX/CNRS,, (c) Site photo taken at the Underwater Archaeological Park of Baia (photo: MiBACT-ISCR**).**

2. Project Approach and Objectives

Being an interdisciplinary project, the first step was the clarification of targets and goals, and how available test sites wrecks were to be used. Various decisions about the serious games, location, era and data gathered, were taken into consideration. Additionally, various discussions about existing VR and AR technologies (Liarokapis 2007) along with implementation feasibility, clarified, but not ultimately defined, the roadmap towards milestones and goals.

2a Data gathering and pre-processing phase

Data gathering along with intellectual property rights, credits and licensing is one of the fundamental pillar for the project. Both 3D as well as supporting data were accumulated by partners, from open sites, published journals and books and partner's archives to support storytelling, narratives, 3D models of sites (Poullis, 2013; Demesticha *et al*, 2014), ships (Castro *et al*, 2015), cargos, probabilistic geospatial analysis about ship routes (Leidwanger 2013), wreck site formation processes, etc. Having all the necessary information, iMARECULTURE is creating and re-using a plethora of 3D models for both ship wreckages and the amphorae, allowing people that way to examine the 3D underwater environment and objects on it. Similarly, a site of Baia underwater archaeological park where a complete 3D model exists (Bruno *et al.*, 2015; Petriaggi and De Ayala, 2015), is being used for the implementation of the AR supported dives.

2b A serious game for understanding ancient seafaring in the Mediterranean Sea

As a pre-visit experience, social platform users will be able to participate in a seafaring game. The aim of the game is to educate the wide public on how the sailing routes were chosen in east Mediterranean during Classical Antiquity and how dangerous and difficult maritime trips were. The player carries cargo across ports trying to maximize wealth against weather conditions and various dangers, to upgrade ship and cargo capacity. The game has advanced storytelling about the various aspects of that time such as ships, life on board, how captains used to navigate their ships according to the sailing season, etc.

The player will take the place of the Captain and will travel the routes that are believed were used, in an educational and fun way. The highlight of the game especially for the young people, is that they are being educated, in an innovating and not traditional way without getting bored. The game is evolving as it goes

revealing insights about the ports and the merchandise that can be obtained. Using the trade system coins and goods that are gathered, the user gets the opportunity to buy more ships and become the main player in the region.

The game utilizes the probabilistic geospatial analysis of the ship routes of the Classical and Hellenistic period through the re-use of open GIS maritime data, ocean and weather data. Naval engineering and sailing diagrams along with the ship routes, are being used as underlying information for the seafaring game.

A game map is created as the route-plotting graph shown in Fig. 2, where each vertex represents a coastal feature, i.e. port, and the edges represent "hops" in a voyage.

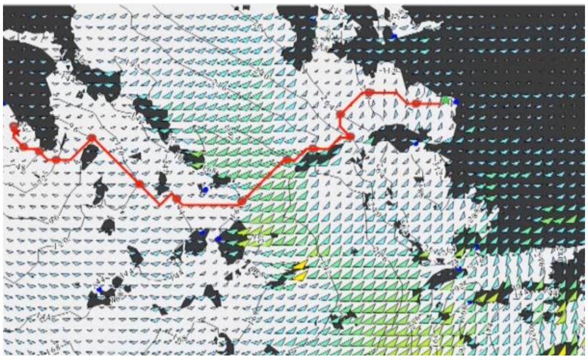

Figure 2. Route creation algorithm in the game map.

The cost function is the edge length, and the heuristic is the distance to the goal vertex. This is sufficient for estimating voyage time, but additional hazard data (piracy, weather, shallow waters, etc.) add depth to the simulated economy by exerting negative incentive along dangerous routes. This could result in high-risk destinations where certain resources are scarce, thus massively rewarding the player due to the correspondingly high demand. Hazard data can be defined discretely for each edge, or sampled from a heat map. The information provided by the archaeologists has been incorporated into the game's project data e.g. port types, piracy areas, density of wrecks, commodity types and their value, ship capacity, etc. Lastly, path-finding is done through minimization problem using approaches such as the A* (Hart et al. 1968) and Dijkstra (Dijkstra 1959) algorithms. Currently the game is still under development under constant circles of evaluation from expert users (Philbin-Briscoe et al. 2017).

2c Virtual UW Excavation

Another underwater serious game is currently under development and will be mainly used for training maritime archaeology students. Users will be trained on the specifics of underwater excavation and familiarize themselves with the instruments in use

(Kouril & Liarokapis 2018), such as the airlift, without the constraints of the underwater environment, which, apart from the time limitations include the difficulty in verbal communication between the student and the instructor. Users will also be able to learn how to document and study wreck site formation processes. By teaming up with an expert, in this case a seasoned maritime archaeologist, students will gain valuable experience and knowledge on the methods, techniques and tools used in underwater archaeology, prior to working at the real site. The focus is not on simulating swimming but on excavating underwater following established archaeological methods and techniques. For the “fun” element of the game, that motivates the user to play the game - we have chosen the treasure hunt gaming approach. The main idea is that one or more players will try to collect as many points as possible by discovering, tagging, surveying and digging items out of the shipwreck. To make the game more interesting, amphorae should be placed pseudo randomly, with some degree of covering by a sandy sea bed. The amphorae placement algorithm is based on the solution presented in (Liarokapis et al. 2017) that places the objects procedurally. The placement of objects is different with every start of the game, however, there are fixed parameters - playing area size and number of amphorae. For our game, we have chosen 25 amphorae and playing area of 20 by 20 meters. The actual placement is done using an exponential function (Liarokapis et al. 2017) (Fig. 3).

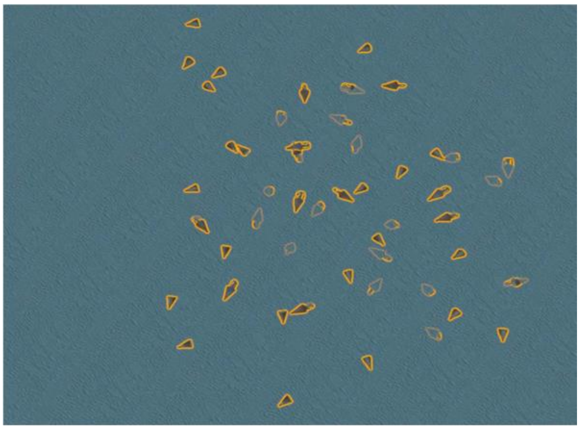

Figure 3. Random object placement in the game scene.

A very crucial element of the excavation game is that the objects should have different degree of coverage by the sandy terrain. Multiple methods for real-time modification of the terrain are available, which would allow the user to dig the objects. The methods differ on their computational difficulty and level of believability. One of the possible approaches, due to the limited amount of interaction the user is doing with the terrain, modification of positions of the vertices of the mesh might be deployed to modify the terrain. However, more universal and correct approaches are available, like the approached that was introduced by Aquilio *et al.*, (2006). The method presents a real-time algorithm to modify the Dynamically Displaced Height Map (DDHM) to record vehicle tracks in sandy terrain. The height map representation also allows the use of other algorithms based on height maps, which would add slippage properties to the soil (Holz et al. 2009).

2d 3D Puzzle Serious Game

As a part of the project it was decided the creation of another serious game related to 3D puzzles of amphorae. The user will gather the fragments he discovered during the VR underwater excavation and either will try to assemble the pieces physically after those being 3D printed or he will try to assemble the fragments in a VR game like in Fig. 4, which is currently under development.

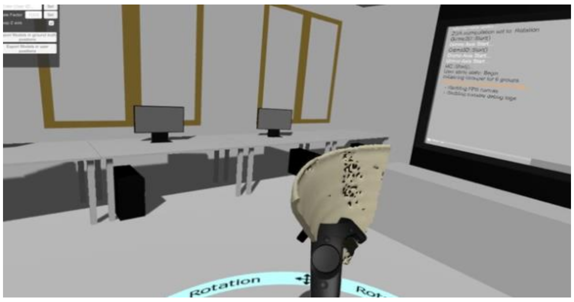

Figure 4. VR 3D Puzzle game

3. Immersive technologies for dry visits

The next big task of the project is the creation of an UW exploration serious game which will allow the dry visit and exploration for the user. The aim of the serious game is to raise people's archaeological knowledge and cultural awareness. It will provide immersive technologies to increase interaction time in an underwater archaeological site, both for the public, as well as, for researchers and scholars. Users can experience an immersive virtual underwater visit using off-the-shelf VR headsets like HTC Vive (on site/museum) or Daydream HMD (at home). Apart from their visit, they can also get some information about the archaeological artefacts through textual descriptions, videos and sounds.

The application was developed in Unity engine with support for VR Head Mounted Displays (HMD) HTC Vive. HTC Vive comes bundled with two motion tracked controllers and laser-based tracking system called Lighthouse which provides 6 Degrees-of-Freedom (DOF) tracking in an up to 4.5 x 4.5 m area with two beacons. This setup, allows users to perceive an immersive underwater experience. The work done for developing the immersive VR environment consists of a) graphics effects (i.e. lightning, fog), b) procedural content (i.e. placement of artefacts), c) behavior (i.e. fish movement) and d) interaction (i.e. exploring and learning) (Liarokapis et al. 2017). As is shown in Fig. 5 the fish behavior is a big part of the immersive UW environment.

Figure 5. Fish behavior in the underwater environment

In the virtual experience, there are two types of fish which have different sizes and speeds, spawning groups of 80 and 100 instances. Fish school simulation implementation was based on the algorithm proposed by Reynolds, (1987). The algorithm simulates flocking behavior boids (bird-oid objects) - birds and other living species, including fish.

The interaction is focused on navigating inside the virtual environment and receiving information about the archaeological artefacts. The user can move within a predefined space in the virtual space. Using the controllers of the HTC Vive device, the user is able to move towards the direction he is facing. Additionally, players can pick up and examine various objects using the dedicated controllers. They can also control the relevant information that they will receive like textual descriptions about an artefact or a relevant video.

Another way to provide immersive experience to museum visitors is achieved by using holographic displays, developed by Holografika (Balogh et al. 2007). Holografika have created a 3D visualization of the underwater scene reconstruction for their light field 3D display. This technology enables users to enjoy the presented scenarios interactively without wearing any cumbersome equipment. The dry visit application developed for the consortium is capable of visualizing complex 3D scenes and provides additional information for various points of interests. After developing the initial application framework, Holografika is currently in the process of testing and optimizing the rendering for the final underwater scenes created for the project.

4. Ship and Amphorae 3D libraries

An additional innovation of the project was the development of the outline and short population of a 3D Library as tools for Maritime Archaeology using ontological schemes. The libraries were decided that were going to be separated into two, one documenting various types of ships and another one for the amphorae description.

4a Ship Libraries

Based on the published literature, three 3D models of vessels that could possibly have sailed the Mediterranean in the 5th and 4th centuries BCE have produced (Fig. 6). To decide some of the features of these models a literature review was conducted of almost all published archaeologically recorded shipwreck hull remains from the Bronze Age to the Middle Ages and a shipbuilding taxonomy was developed that are still being explored with the intention to produce a book and the preliminary research is presented in (Castro and Juan, 2018).

Kyrenia is the first ship, which its drawings were produced by Richard Steffy, Michael and Susan Katzev. And with use of TLS at Kyrenia II Liberty at Thalassa museum a 3D model of the ship was created. The second ship was the Ma'agan Michael which was recreated using drawings of the ship that they were created by Shalev & Kahanov. The third ship that was 3D reconstructed is the Athenian Trireme (Ward et al., 2001).

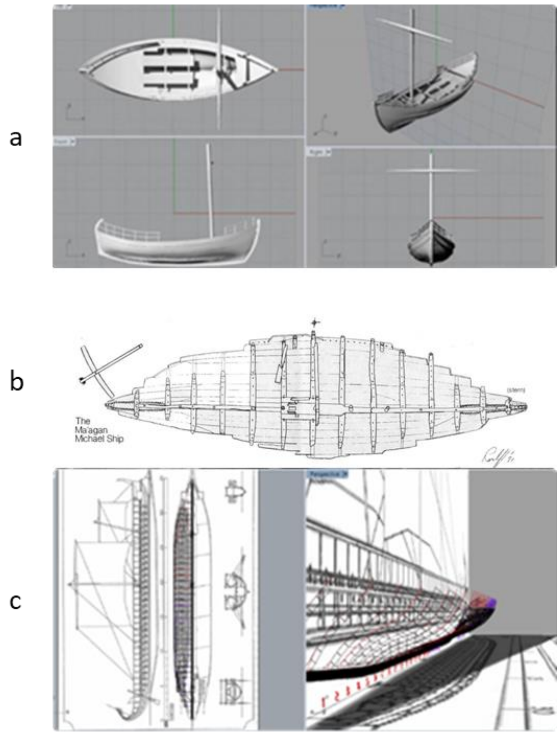

Figure 6. (a) Kyreneia Ship, (b) Ma'agan Michael, (c) Athenian Trireme, Credits: UNL, (Castro & Juan 2018)

4b Amphorae Libraries

Using an ontology - based approach (Fig. 7) for modeling and storing archaeological artifacts is one of the goal of the project in order to pull together various information and possibly to automatically derive 3D models that are based on this particular design (such as slightly larger or smaller hulls). During the research that was conducted (Drap et al.

2017), an ontology for cultural heritage modeling with an orientation towards 3D photogrammetric representations and spatial measuring has been proposed. That translates to, resources being represented from the measurement point of view and can access all the photogrammetric data that contributed to their measurement in space.

For the amphorae ontology-based profiling, three dimensions of profiling were distinguished: Typological (height, maximum diameter, volume), Photogrammetric process (bundle model, camera, photographs) and Spatial (position, convex envelope). For the linking of data, the ontology was aligned to the CIDOC-CRM ontology to provide more integrity between cultural heritage datasets and to allow more flexibility for performing federated queries cross different datasets.

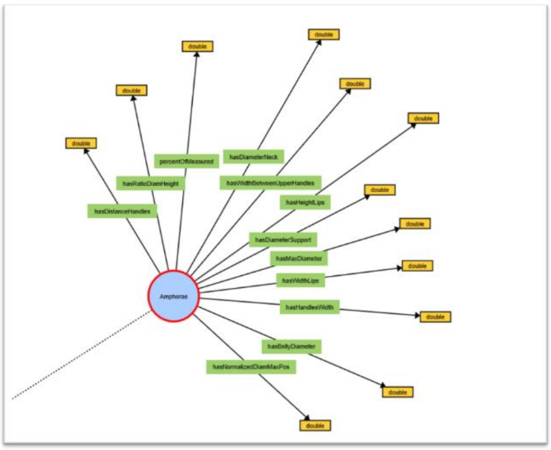

Figure 7: Amphorae profile, Credits: CNRS

5. Underwater Augmented Reality

In order to enhance the experience of an underwater visit through the projection of digital content into users' real environment, the potential of AR has been discussed in various research contexts (Bordegoni *et al.*, 2008; Han, Jung and Gibson, 2013; Hammady, Ma and Temple, 2016) . AR's increasing potential for the tourism industry and the enhancement of the tourism experience did not remain unnoticed. Using markers along with standard sensors of tablets/phones with acoustic beacons, the location-based AR applications would help tourists to receive instant information on unknown surroundings that contribute to provide a new learning experience.

Various systems and technologies for underwater AR have been tested before iMARECULTURE. Such systems are HMDs (Morales et al. 2009) for navigation and orientation of divers underwater by augmenting their vision with artificial horizon and visual aids to provide a guideline and help them with their work. Other systems for underwater AR include a device for AR that allows users to play simple games underwater as it has been introduced in (Bellarbi et al. 2014). Additionally Oppermann, Blum and Shekow, (2016), use tablets placed into a waterproof case, and develop a game for kids that helps them to improve their swimming skills in a swimming pool.

Until recent, the only attempt to adopt AR technology directly in the submerged environment for the exploitation of UCH is represented by the VISAS project (Bruno *et al.*, 2016a; Bruno *et al.*, 2016b). The developed AR system consists in an underwater tablet equipped with an underwater positioning and orientation system that guides the diver tourists during the diving session while providing information about the archaeological artifacts spotted during the visit.

The technologies developed during the VISAS project were being exploited and extended in iMARECULTURE project for the implementation of an underwater AR application. The application consists of an underwater tablet equipped with a hybrid tracking system that guides the diver during the exploration, while visualizing an AR layer that shows labels or 3D contents representing the current or the original aspect of the site. The underwater AR interface will be capable of superimposing different types of visual information (i.e. 3D, metadata, images, videos) over the images captured by the tablet main camera. The divers who visit the underwater archaeological site will have the possibility to see their position over the site map and enjoy a hypothetical virtual reconstruction of the structures to better understand their original aspect and their function. The UI (fig. 11) will provide also a command button that will allow users to switch from the 3D model of the archaeological remain to the 3D model of a hypothetical reconstruction of the artefact.

5a Dehazing

To increase the perception of the underwater scene, the AR application will allow to improve the vision of divers by using dehazing techniques to correct the effects of fog and haze underwater. Many algorithms were developed to dehaze input images (He, Sun and Tang, 2011; Zhang and Yao, 2017; Gao, Li and Wen, 2016).

The workflow of the AR dehazing architecture is shown in Fig. 8 below.

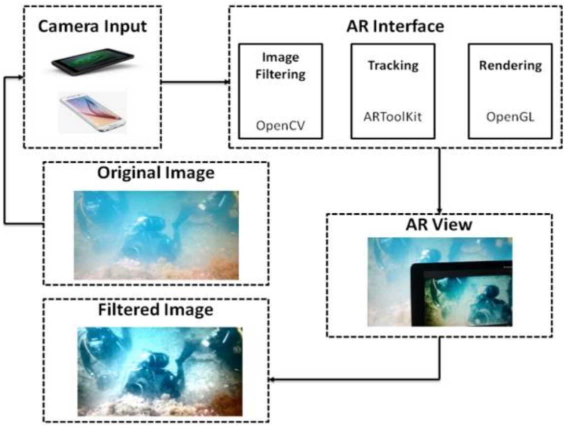

Figure 8. Augmented reality dehazing architecture

At first, the input image coming from the tablet camera is filtered and improved to reduce defects and other imperfections caused by turbidity or poor lighting conditions. This preprocessed image serves in the second step as input for the detection of objects in real world that will be used by the AR tracking algorithm. Following that, objects of augmented reality are composed together with improved preprocessed input image and rendered into an output image. This image is then displayed on the screen of the tablet.

The AR dehazing algorithm was tested on several videos taken in underwater environment. The videos were played on a monitor of a PC, and a tablet was used to record, process and display the images. The tests were done with a NVIDIA Shield K1 tablet and Samsung Galaxy S6 phone. The preprocessing step took 7.8 milliseconds on the tablet and 9.0 milliseconds on the phone, which in both cases allowed the application to present improved images in real-time (Žuži et al., 2018).

5b Image enhancement tool

One of the main scopes is the development of a Virtual Reality environment that reproduces the appearance of underwater sites in the most accurate way, while making it possible to visualize the archaeological remains as they would appear outside of the water. To accomplish that, a comparison of various image enhancement algorithms was done to figure out which one performs better nuder different environmental and illumination conditions. Five state-of-art algorithms were selected and used to enhance several dataset of various underwater sites and heterogeneous conditions (depth, turbidity and lighting). These enhanced images have then been evaluated by means of quantitative and qualitative metrics (Mangeruga et al. 2018). There are several different metrics known in scientific literature employed to evaluate underwater enhancement algorithms.

The selected algorithms that were selected for the image enhancement were the Automatic Colour Enhancement (ACE), Contrast Limited Adaptive Histogram Equalization (CLAHE), Colour Correction Method on lab Space (LAB), Non-Local Image Dehazing (NLD) and Screened Poisson Equation for Image Contrast Enhancement (SP).

Regarding the methodology Mangeruga, Cozza and Bruno, (2018) tried to produce a dataset of images that was as heterogeneous as possible, in order to better represent the variability of environmental and illumination conditions that characterizes underwater imagery. Furthermore, they have chosen images taken with different cameras and with different resolutions, because in the real application cases the underwater image enhancement algorithms have to deal with images produced by unspecified and varying sources. The visual results of the applied algorithms are shown in Fig. 9 and Fig. 10 below.

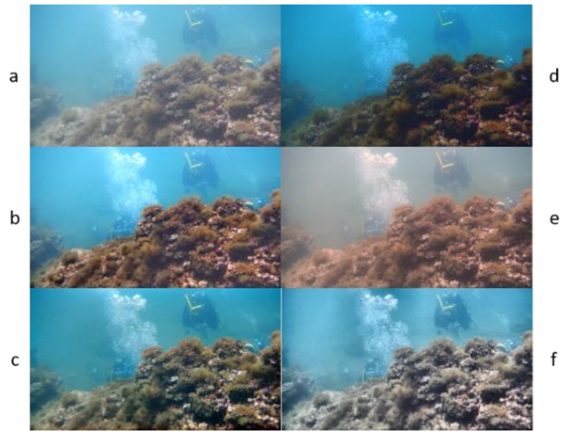

Figure 9. (a) image Baia 1, Credits: MiBACT-ISCR; (b) Non-Local Dehazing; (c) Screened Poisson; (d) Median Dark Channel Prior; (e) Lab Colour Correction; (f) Clahe

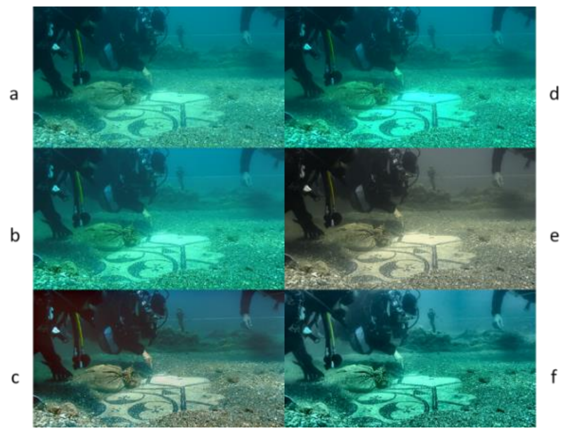

Figure 10. (a) image Baia 3, Credits: MiBACT-ISCR; (b) Non-Local Dehazing; (c) Screened Poisson; (d) Median Dark Channel Prior; (e) Lab Colour Correction; (f) Clahe

5c Hybrid underwater tracking solution

The implementation of the AR application requires the development of a solution to calculate the position and orientation of the tablet in the submerged environment. To do so, a hybrid solution that merges data generated by visual tracking techniques (both marker and model based) using applications such as ARCore and ARKit, with data from an acoustic modem is integrated with the underwater tablet, which estimates the position of the receiver by computing the distance from at least three fixed transmitters (beacons) placed on the seabed (Fig. 11). Moreover, data coming from an inertial platform and a depth sensor are used to improve the accuracy and increase the robustness in case of loss of signal from one or more beacons. The data coming from the various sensors are processed through Kalman filtering.

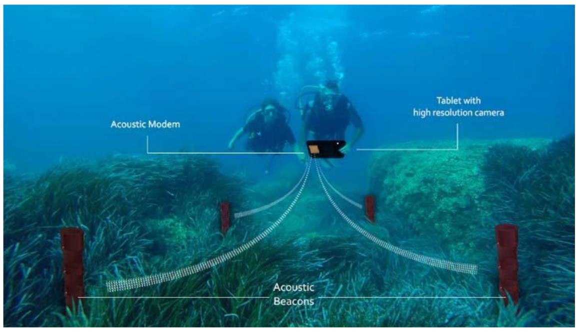

Figure 11. Augmented Reality system, (Bruno et al. 2017)

The tablet is composed of two major parts: a fully functional underwater touchscreen housing and a waterproof case for the electronics of the tracking system. The two devices are connected using a Wi-Fi interface.

The tablet updates the diver's position and orientation on the 3D map at a frequency of 50 Hz. The current position is estimated through an Extended Kalman Filter that uses the distances from each beacon, the depth provided by a pressure sensor, the accelerations along x, y and z axes, the orientations provided by an inertial platform and the position and orientation data provided by the visual odometry algorithm. The distance between the tablet and a beacon is computed using the time-of-fly of the acoustic wave.

To this end, the acoustic modem on the tablet sends a two-way range command to the remote beacon and starts an internal timer. When the tablet receives the response message, sent by the beacon, the timer is stopped. The tracking system sends cyclically a two-way range to all beacons. shows the localization algorithm.

6. Conclusions

This paper has presented the advancements of iMARECULTURE project and brief results of the first year. The project is characterized by the integration of different disciplines and research activities in the areas of 3D acquisition, underwater VR environments, underwater AR, serious games, GIS, marine archaeology and interactive storytelling. This synergy aims in creating innovative applications and digital experiences in support of Virtual Museums, to empower different types of users to engage with European underwater cultural heritage digital resources.

The first year was devoted to data acquisition and data preparation. Over the second year, most of the applications will be under development and constant evaluation. In fact, interaction among development and expert's evaluation is constant, causing delays on one hand, but keep a high degree of historical and archaeological accuracy, necessary for projects funded under EU H2020.

Particularly, the paper presents a VR application for underwater exploration and the first steps in the development of two serious games: one devoted to the simulation of ancient seafaring practice through the Mediterranean Sea and another one for the simulation of underwater archaeological excavation. Moreover, the development of an underwater AR system has been presented. The system is based on an underwater tablet coupled with an acoustic localization device. The AR software will manage the image enhancement issue and will perform a hybrid localization by combining data generated by the acoustic device and by an optical tracking algorithm.

The most ambitious and interesting in technical terms task is the development of underwater AR, with its hybrid tracking system, using visual odometry, acoustic positioning and sensors from the smart devices (tablets and mobiles) used.

Despite the technologically demanding context of the project, the main issues confronted so far, are irrelevant to technology. The first one rises from the multidisciplinary of the project which must carefully balance between 'fun' factor and archaeological accuracy. The second one is about the complexity of Intellectual Property Rights (IPR), involving many creators along the process line. iMARECULTURE, being a non-profit action may override the 'Property' aspect of the IPR, but still there are several ethical aspects concerned, even when using published material.

Acknowledgement

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USING REAL-TIME ENGINES & PHYSICALLY BASED RENDERING FOR INTERACTIVE ARCHAEOLOGICAL VIRTUAL RECONSTRUCTIONS. A CASE FROM THE HOUSE OF THE MOSAICS IN ERETRIA.

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Περίληψη

Η έρευνα αυτή διερευνά τη δυνατότητα επίτευξης φωτορεαλιστικών αποτελεσμάτων σε πραγματικό χρόνο μέσω της χρήσης μηχανής ανάπτυξης παιχνιδιών επόμενης γενιάς, με στόχο την περαιτέρω χρήση τους σε ψηφιακές αναπαραστάσεις του παρελθόντος. Ο συγγραφέας βάσισε την έρευνά του σε αρχαιολογικά τεκμήρια με την καθοδήγηση ειδικών επιστημόνων, και διεξήγαγε πειράματα, προκειμένου να αναπτύξει το έργο. Σε αυτό το πλαίσιο, δημιουργήθηκε μια ψηφιακή βιβλιοθήκη υφών υψηλής πιστότητας, κατόπιν της διεξαγωγής μετρήσεων και φωτογραφήσεων, και ακολουθώντας μεθόδους τεκμηρίωσης χρώματος. Προκειμένου να ολοκληρώσει αυτό το έργο, ο συγγραφέας δημιούργησε την τρισδιάστατη ψηφιακή αναπαράσταση της Οικίας με τα Ψηφιδωτά της Ερέτριας. Η συγκεκριμένη ανακοίνωση παραθέτει μια σύντομη περιγραφή των στόχων, μεθόδων, διαδικασιών και ευρημάτων της έρευνας.

Abstract

This study explores the possibility to achieve real-time photorealistic results by using next generation game engines, aiming at further using them in digital reconstructions of the past. This research is based on archaeological evidence and scientific advice and the author conducted experiments in order to develop the project. A digital library of high-fidelity textures was created by obtaining the accurate physical materials, by performing measurements and photo shootings, and by following color proofing methods. In order to accomplish this task, the author created a 3D digital reconstruction of a monument: The andron of the House of the Mosaics in Eretria. This paper provides a brief presentation of the research aims, methods, procedures and findings.

Λέξεις Κλειδιά/Keywords: real-time rendering, photorealism, Virtual Reality, House of the Mosaics, game engine, Eretria

1. Introduction

Since the mid-19th century, when the science of archaeology was essentially founded, up to today, imaging methods and recording findings have evolved. Sketches and photos have been succeeded by computers and by other technologies that are used in three-dimensional digital mapping. Today, the findings can be scanned three-dimensionally (3d scanning), be digitally modeled with the help of photogrammetry or can be reproduced in 3d modeling software.

The three-dimensional digital survey of the findings constitutes the first step towards the main objective of archaeology: the reconstruction of the past. The next step is to restore the findings in their original form so that they become accessible to the general public in order to preserve the cultural heritage. An ideal medium is digital representation. "When we see a representation of the past, we place ourselves within history. Through the visual experience of the past we are able to shape and alter our perception of history and consequently our picture of the world and ourselves" (Sideris, 2012).

Figure 1. House of the Mosaics: Andron and anteroom. Real time rendering in Unreal Engine 4

Using the latest technologies in the fields of 3d graphics and video games that we have now at our disposal we can move beyond the digital representations. We are able to reconstruct the past by creating photo-realistic interactive applications that place the user "in vivo" within history and transform him from a mere spectator to the protagonist by offering an immersive experience.

2. Aims of research

The project deals with the creation of archaeological Virtual Reality (VR) visualisations using the latest real-time three-dimensional technologies used in video games. It is hypothesized that: a) Using the real-time cutting-edge technologies that appeared during the last two years (Physically Based Rendering & lighting) and have been incorporated in 3d game engines, it is possible to have photorealistic results in real-time. This capability, in combination with the interactivity offered makes game engines ideal for creating archaeological Virtual Reality applications and b) The collaboration of creative media artists and archaeologists improves research and teaching in the field of archaeology.

The following questions were used to support the stated hypotheses: a) Is it possible to achieve photorealistic rendering in real-time? b) Is it possible to use game engines in creating archaeological VR? c) What background should somebody have to be able to create an archaeological virtual reality application? d) Is the collaboration between artists and scientists, between two such different worlds, possible?

3. Fields of research

The development of an interpretative VR project is a process that requires research in a number of areas, considering that the monument has to be re-built entirely in its initial (hypothetical) form and appearance. Research was conducted in the following areas:

Archaeological Research

Location: history, urban planning, activities, physical lighting, ambient sounds.

Architecture: lighting, houses, rooms, doors & windows.

Room decoration: wall decoration, colours, mosaics.

Furniture: couches, tables, footstools.

Materials: wood, fabrics, clay, metal, glass, ivory, varnish, dye, paint.

Objects: drinking vessels, utensils, lighting props (lamps/lampstands)

Technical Research

3D modeling techniques: polygon modeling, digital sculpting, 3d scanning, photogrammetry, cloth simulation.

Real-time rendering - Physically Based Rendering (PBR): materials and lighting (IBL).

Real-time engines: pricing, PBR material & lighting integration, scripting, audio capabilities, user interface authoring tools, target platforms.

The author based his research on archaeological evidence and scientific advice as well as conducted experiments in order to develop the project: an archaeological interpretative Virtual Reality application.

4. Methodology

The research strategy for this project, a case study, was strongly practice-based and included a) experimental elements and b) a variety of data derived from documentation, direct observations, interviews and the project.

The combination of these data collection methods aims at crosschecking information, supporting the project creation and extracting conclusions to check the hypothesis.

4a The research on materials

During the 4th century B.C. the House's rooms were built with a variety of construction materials, like stone, pebble, mud-brick, wood, plaster. The furniture and objects in the rooms were made out of wood, metal, ivory, fabric, glass. In some cases, the use of pigment or varnish was made, derived from mineral or organic substances. Since the beginning, the author had realized that in order to create the most accurate possible representation, extended research on materials should be carried out first and foremost.

4b Experiments and Digital Library

The purpose of the experiments was to establish the correct model reconstruction, either through information or conclusions, or by utilizing the experimental objects themselves as reference material.

Prior to proceeding in 3D modelling and texturing of the site and objects, a series of experiments were conducted with a selection of: wood types, pigments, varnishes. The selection of natural materials was based on the needs of visualization and their use, as mentioned by ancient writers and marked by researchers.

For this purpose, a library of high-fidelity textures was created by obtaining the accurate physical materials, by performing measurements and photo shootings, and by following color proofing methods.

5. The Case Study

The House of the Mosaics in Eretria was built around 370 B.C. It stands out thanks to its floors, four of which are decorated with beautiful elaborate pebble mosaics, bearing mythological, herbal and efflorescent decoration. The author's digital restoration includes the rooms with three of the above-mentioned mosaics. The anteroom and andron of the House of the Mosaics have been marked by Swiss archaeologists as rooms 8 and 9 respectively and are the most spectacular rooms of the House (Ducrey et al., 1998). Currently, only the stone foundation, the door's threshold and the mosaic floors are survived, all in very good condition. The archaeologists of the Swiss School of Archaeology in Greece have moved to the restoration of the rooms, having constructed a scale model, currently exhibited at the Archaeological Museum of Eretria. The mosaic rooms are housed by a pavillion for protection (Reber, 2007).

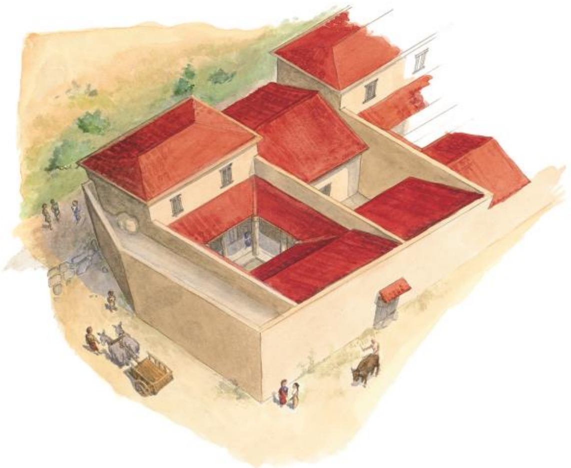

Figure 2. House of the Mosaics.

6. Construction of the digital architectural model

The construction of the digital architectural model was based on blueprints, books and documents provided to the author by the Swiss School of Archaeology in Greece, and also on the model exhibited at the Archaeological Museum of Eretria, the local research of space conducted by the author and the triangulation of findings from other houses.

6a The walls

The total area of walls' inner surface of rooms 8 and 9 is 202.47 square meters (as measured by the measure utility of 3ds Max). According to the sketches of the archaeologists and the findings triangulation with other walls of Hellenistic rooms in Eretria, Delos and Pella, the walls of rooms 8 and 9 are coated with plaster, moulded to resemble marble revetment (orthomarmarosis).

Figure 3. Eretria. Decorated plaster of the walls on a villa.

In the case of the museum's model, walls are painted with vibrant colours, red, yellow and black. The width of the "stones" is 105cm approximately and their height varies.

Concerning the texture resolution, the author had set a target of minimum texel density at 1024 pixels/m. In order to preserve this level of detail, he should find ways to cover such a large area with texture map and preserve resolution at the same time. The final selected process has as follows:

- A detailed high-poly model of a part of the wall was created.
- Using the render to texture workflow the details of the high-poly model were baked in a series of maps: normals map, height map, ambient occlusion map.
- In the next stage, these maps were edited and manipulated in Adobe Photoshop and were later used as a base to create the texture maps to be later fit in the wall material following the *thirding* method. Meanwhile, masks were created following the texture packing method to set the areas of each colour.
- In addition, detail texture maps were also created, with plaster details for cases where the player camera zooms at the wall.
- Moreover, a dirt texture map was created, which helped in turning the appearance of the wall more natural.

6b The mosaics

The mosaic floors in rooms 8 and 9 are two of the first-ever mosaics created in Ancient Greece. The andron's mosaic is survived intact, except from some pebbles or small parts missing. The anteroom's mosaic missed a large part at the left side, which appears to have undergone subsidence.

The first step of the process was to manipulate the photos provided by ESAG to the author. In the case of room 9, the photo was manipulated aiming at eliminating the deformation and prepare it to be later integrated in the 3d model. In the next step, colour corrections were applied to add uniformity to the photo (reduce the tonal and colour gradient created due to the shot). In the case of room 8, no quality photos were available, or some photos of medium quality only illustrated part of the mosaic. In addition, a large part of the mosaic is not survived. Thus, a different approach was employed by the author, moving to the digital restoration of the mosaic by recreating the missing parts from scratch, using data from the survived parts as source. In addition, the floral patterns of the strip skirting the central theme of sphinxes and panthers, were digitally restored using pebbles of the mosaic of room 9.

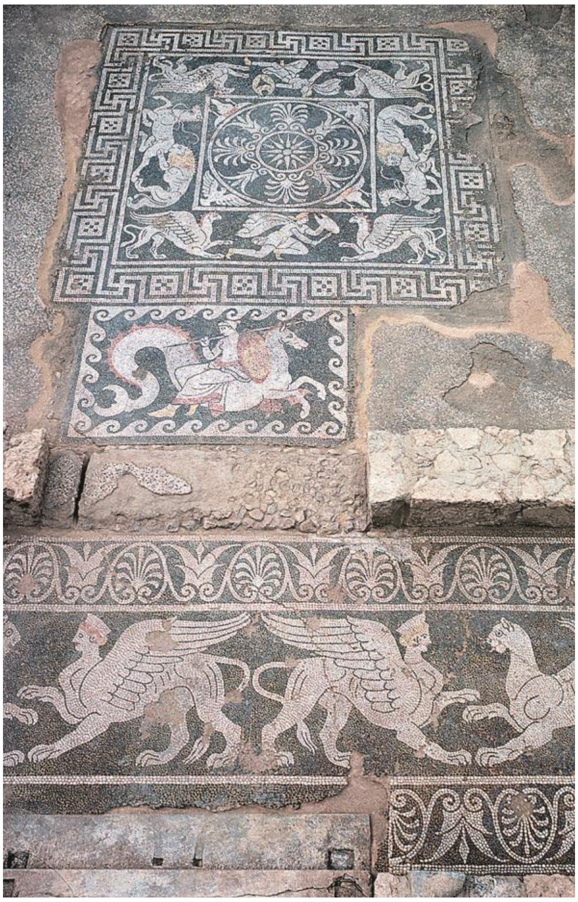

Figure 4. House of the Mosaics. Existing mosaic floor.

Figure 5. Digital restoration of the mosaic.

The restored images were used as diffuse textures. In the next step, heightmaps were created in order to illustrate the embossed appearance of the surface on the 3d material. For this reason, the pebbles needed to be detached from the grout. The author experimented with several workflows to detach the pebbles from the grout. However, none of the tested workflows returned the expected results. Thus, the pebbles were painted one by one in a new layer, which was later used as mask, a time-consuming process, yet essential to illustrate in accuracy the embossed surface.

Finally, using the pebble mask as a base and by applying filters and effects, new maps for height, normals and ambient occlusion were created. The height map was also used as a base for the roughness map.

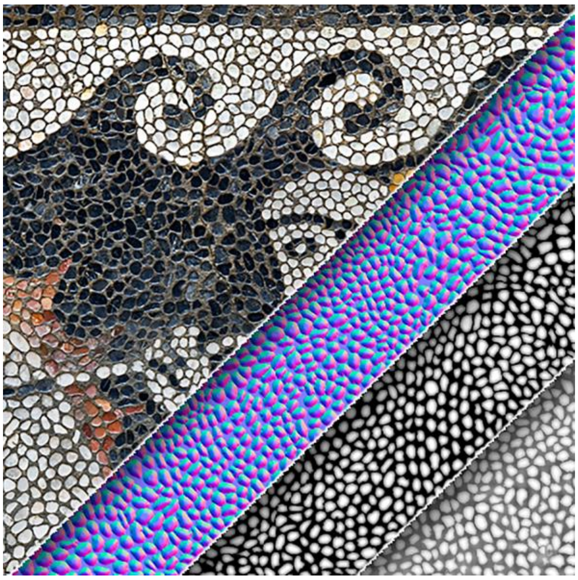

Figure 6. Texture channels (Diffuse, Normals, Height, Ambient Occlusion).

6c The doorway

The marble threshold at the entrance of the anteroom is typical of the Hellenistic thresholds, with the distinctive sockets and channels used to support the cladding and the separation of the upper part in two levels (Haddad, 1995). The threshold is the only rescued part and to restore the entire doorway, the author used analogies and formulas mentioned by Vitruvius (Vitruvius and Granger, 1983) and also the tables and conclusions quoted by Dr. Haddad (Haddad, 1995).

7. Furniture and props

Few remains of furniture and other props located in the ancient houses have survived. The main reason is that the manufacturing materials either didn’t manage to resist time decay or were recycled to create new objects. To (re)construct the furniture and props, the author consulted the experts, referred to relevant bibliography and studied illustrations of objects on pottery and sculptures.

7a The couch (kline)

Couches and tables are the furniture that appear more often than any other on Greek pottery and also on many reliefs. A large number of stone replicas of wooden couches have been discovered in Hellenistic era tombs. In some cases, except from the furniture, also mattresses, bedding and pillows are illustrated in detail (Huguenot, 2008). Details of the couch are often depicted with colour on marble (Sismanidis, 1997). No wooden couches have been survived from Hellenistic Greece. However, ornaments of ivory, glass, ceramic or other material have been discovered.

Starting with the above-mentioned sources, the author created a prototype couch, bringing together all basic features of a Hellenistic couch.

Figure 7. Kline rendered in real-time in Unreal Engine 4

First, the author created a high-poly 3d model in 3dsMax, mainly applying the subdivision surface technique. The legs were based on marble replicas of the couches, discovered in the Macedonian tombs Pydna I, Neon Kerdyllion, Potidaea and in the findings of the Vergina II tomb (Sismanidis, 1997). In the indentation located on the horizontal crosspieces, a relief with griffins and rosettes was created based on the paintings of the couch in the tomb of Potidaea, following the advice of Dr. Athanasios Sideris. The matress and pillow models were based on the marble replicas in the tomb of Amarynthos and also on pottery illustrations, while the covers were constructed with linen fabric (Huguenot, 2008), (Andrianou, 2009). The physical pillow created by the author was used as reference.

For the 3d materials, the author used beech wood for the couch, while the indentations on the horizontal crosspieces were created with maple wood. The materials used to create the legs’ ornaments, the griffins and rosettes are ivory, gold leaf and glass. Some parts of the couch were painted with red ochre, while the bare parts of wood were believed to be covered with linseed oil. For the linen bedding and pillows, the author used the colour palette of the painted marble replicas in the tomb of Amarynthos (Huguenot, 2008). During the whole process of the project, Dr. Athanasios Sideris supplied the author with information on materials and the final appearance of the couch.

The high-poly model of the couch could not be used in the real-time application due to the very high mesh resolution (1.000.000 triangles approximately). For this reason, the author applied the render to texture method on a low-poly model, created from scratch based on the high-poly model. In this way, the couch model was reduced to 10.000 triangles, without altering the visual result. The triangle count could be reduced further, but the couch plays a leading role in the project. As later proved following several preliminary tests, Unreal Engine 4 could easily support this triangle count.

Figure 8. Kline foot optimization using normal maps and *render to texture* workflow.

7b The table (trapeza)

As with the case of couches, tables are quite often depicted in vases, while many stone life size replicas have been survived. The most typical type is the one consisting of a rectangular oblong top, standing on three legs, with their lower ends sculpted as lion feet. In the upper part, the legs are attached to the top with decorative nail heads (*ephylis*) and are interconnected among each other with a t-shaped wood construction. The three legs secure better steadiness when tables are placed on bumpy floors, like pebble mosaics.

The dimensions of the table model created by the author are 100x48cm and the height is 52cm. It is created with maple wood, while the decorative nails are brass. A survived metal table leg, currently exhibited at the Archaeological Museum of Palermo (Richter, 1966 fig. 204, left) was used as reference.
The process followed by the author to create the digital model is similar, if not identical, with the process followed in the case of the couch.

Figure 9. Trapeza rendered in real-time in Unreal Engine 4.

7c Oil lamps and lampstands

The oil lamp was one of the most widespread used light fixtures in Ancient Greece. It was typically used indoors. Oil lamps in the Hellenistic period are most commonly ceramic. The wick was manufactured with flax strings, while the most common fuel was olive oil (Moullou, 2010). Oil lamps were placed on tables or on dedicated lampstands. Following research it turns out that, although oil lamps light cannot compete with modern lighting means, it is effective and inexpensive given that the light sources are placed accordingly in space (Moullou, 2010).

Figure 10. Virtual reconstruction of a lampstand.

In the andron of the House of the Mosaics oil lamps were placed on tables and on lampstands. The digital models were created following the subdivision surface modeling technique. The flame was created in Unreal Engine 4 with particle systems and textures produced by the dedicated photo shooting of the author’s oil lamp.

Figure 11. Lamp flame photo shooting

For each lamp flame in the Unreal Engine 4 a point light was created in order to build the illusion that the flame sends out light. For the point light, an ies light profile was encoded by the author in Notepad++, by using data from tests and calculations executed by the Lighting Laboratory of National Technical University of Athens (Filippopoulou, 2010).

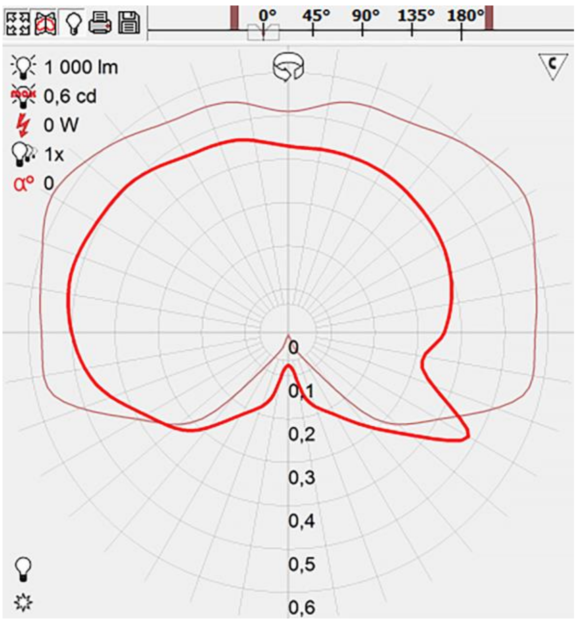

Figure 12. Diagram of a light profile encoded by the author in ies format.

7d Drinking cups and plates

The symposion was one of the favourite entertainment ways of Greeks. It was a friends gathering, a party as we call it nowadays. In the symposia, which were usually held in andrones, like room 9, the attenders used to eat food and drink wine. The process involved different vessels, other dedicated to wine, water and their mixing and other dedicated to serving food and wine.

The author created the models of several drinking cups and plates, which were placed on tables, their natural place during the symposion.

8. The engine

The technological development in the field of video games since 2013 onwards have led the development of game engines to the stage of the "Next Generation Game Engines", as it is called today. The most popular game engines are Unreal Engine 4, CryEngine V, Unity 5, Amazon Lumberyard (based on CryEngine). The basic feature that differentiates them from the previous editions is the Physically Based Rendering feature, which "models light-material interaction based on real-world behavior" with the use of "more complex BRDFs, Fresnel, normalization of specular highlights, energy conservation in general" (Schultz, 2014). All the above-mentioned facts turn real-time graphics photorealistic and further enhance the immersive experience in a photorealistic application.

8a Asset workflows and engine integration

The 3d models created for use in video games or other real-time applications must be optimized (mesh resolution, texture resolution, number of texture maps) in order to achieve the desirable performance and fulfill the developers' target. The author applied the workflows established by game artists:

- The 3d models were either originally created with low triangle count or two models created for the same object, a high resolution mesh and a low resolution mesh and then the render to texture workflow was applied.
- In all cases, the texture maps that were used had an image resolution based on the power of 2 rule (PoT). To save texture RAM space and reduce draw calls, when possible, the channel packing workflow was applied, as suggested by Epic (Epic Games a, n.d.).
- A dedicated UV coordinate set was created for the lightmap in all the 3d models.
- PBR materials were created based on the reference material charts (Lagarde, 2012/ Karis, 2013/Wilson n.d.).
- The 3d models were converted to fbx format and inserted in the Unreal Engine based on the instructions of Epic on static meshes. (Epic Games b, n.d.).)
- The texture maps were separately inserted in the game engine and the materials were recreated in the Unreal material editor.

8b Application Development

For the application development, the author used the first person template as a starting point. In the next step, he modified the first person character blueprint and added nodes, to offer the user the option to zoom in and crouch. These additions were estimated as necessary by the author, in order to allow the user to check/observe the objects.

Figure 13. Unreal Engine 4 authoring environment.

By the stage when all models were in place and after conducting several lighting tests, the author applied the light building technique, by using lightmass (Unreal Engine's lighting component). Moreover, the post process volume was modified and several effects were fixed, like light shafts, specular bloom, light adaptation etc.

To offer the viewer an accurate image of space and of the ancient ventilation system, the author created a cinematic intro, using camera travelling, starting from the atrium, entering the building through the anteroom's window and following a path through the pillars supporting the roof, to ultimately arrive inside the andron and hand over control to the user to continue his tour.

In the next step, the author created a second level including the main menu. This is also the start level when the user runs the application. For the background, the author created a synthesis of architectural elements from the couches and a modified mural illustrating a symposium rescued from the Macedonian tomb of St Athanasios. An ambient music together with the above prepare the user for the main level following by clicking start.

Overall, the use of Unreal Engine was easy, while the online documentation helped the author overcome any obstacles.

9. Findings

9a The collaboration between visual artists and archaeologists

With this project, the author aimed at demonstrating the fact that when visual artists cooperate with scientists, overcoming prejudice and maximizing the use of available technological means, then the result will be quite rewarding for both sides involved.

From the beginning of the project, the author became excitedly aware of the fact that the scientific community had overcome any prejudice. During research, a plethora of scientific documents had been discovered by the author, written by mainly younger Greek archaeologists, oftenly with studies abroad, which endorsed the used of 3d graphics and overall in favour of new technologies. These documents emerge in their majority from 2010 onwards, leading to the conclusion that the ambience started changing during the decade 2000-2010. The author attributes change to the following reasons:

- The development of 3d graphics technology which convinced scientists that they can bring out monuments through photorealistic representations.
- During the above-mentioned decade software allowing the generation of real-time archaeological applications were published.
- The Foundation of Hellenic World widely established a positive attitude towards archaeological VR, with several archaeological and historical educational interactive applications presented at the “Kivotos” cubeVR and the “Tholos” dome theater.
- Greek scientists were positively influenced by the developments abroad and also by their peers in branches of archaeological schools in Greece.

The above-mentioned conclusions were also substantiated by the meetings of the author with consultant scientists on the project. They all demonstrated a quite positive attitude and interest on the author’s project, they lavishly provided the author with advice and information and appeared familiar and friendly towards new technologies. In addition, the final result pleasured them and fulfilled their expectations in both its scientific and artistic sides. The author, as a visual artist, believes that his cooperation with the experts was exemplary, proving his original hypothesis on the cooperation between visual artists and scientists.

9b Interpretative Virtual reality

Only the floor and foundation are survived in the monument that constitutes the subject of the project. The same thing happens in the vast majority of the monuments of Ancient Greece and other countries. In this case, it was clear to the author from the beginning that the Virtual Reality to be created would be rather interpretative than documentary: "Since we will never know fully and in all details the components of a bygone world, the utmost we can aspire in virtual recreations, is a plausible antiquity, not the real one. A virtual antiquity which will combine the hard data with considerable amounts of ‘learned guessing’. By ‘learned guessing’ some scholars use to mean the choices they are making half-based on the overall knowledge of the relevant cultural context, and half-based on some kind of ‘specialist’s intuition’" (Sideris, 2008).

In the course of the project, the author gradually realized that the creation of an interpretative VR demands wide research and the participation of experts, being two necessary requirements, providing the visual artist the information required to reconstruct the digital models of the archaeological findings as they were in their original form: reference material on volume, forms, colour and surface texture of the objects he is supposed to recreate. In addition, equally useful is information on location, weather and the surrounding environment, as it affects elements, like lighting, or building and object decay. During the course of the project, it was prooved that a big part of available time needed to be dedicated to research and documentation.

9c Modeling and texturing techniques

Following different tests and approaches on creating the 3d models, the author reached to the following conclusions:

- The polygon modeling and subdivision surface modeling techniques proved to be the most appropriate for the creation of hard surface models, like furniture and vessels, which are the most complicated objects in the representations of space. Those techniques offer high levels of accuracy in the creation of high-poly models and also prospects in the later creation of low-poly models out of them.
- On the contrary, digital sculpting did not offer accuracy for the creation of hard surface objects (by contrast to the organic models, where it is more suggested than polygon modeling).
- In the case of fabrics, the cloth simulation technique proved to be faster in relation to the polygon modeling or digital sculpting. In addition, this technique turned out more believable results in the case of the 3d models of pillows and bedding.
- Photogrammetry is a method of surveying and can be applied only on objects that have been rescued in their entirety. In the case of the project, the use of 3d scanning or photogrammetry for the modeling of objects was impossible, as the actual objects have not survived. In addition, even if they were rescued, it is almost certain that they would have been subject to decay due to time and their appearance wouldn’t be true to their form during the hellenistic period.
- The process of modeling and texturing the mosaic floors proved to be the most time-consuming process in the whole project. To accurately represent their surface, the author moved to the digital restoration of the mosaics’ missing parts and next created a height map. In the following stage, the author created a mask, by painting the surface of the pebbles one by one (over 100.000 pebbles). Other methods tested to accelerate the process, did not turn the desirable results. The only different approach would be the use of a 3d scanner, which is not available to the researcher at the time being. However, even in this

case, the mosaics would again need to be digitally restored, a more difficult process when the scanning model consists of millions of polygons.

- The render to texture process (texture baking) is a time-consuming yet necessary process for the creation of models that will be used in real-time engines and virtual reality applications. It is the only way to transfer detail from the high-poly to the low-poly objects, achieving significant polygon reduction. Indicatively, the leg of a couch was reduced from 151772 triangles to 2350 triangles (1,54% of the original model), without any change noticable by the viewer.

9d Physically Based Rendering (PBR) and photorealism

Through the process of the present research and also through his experience on Physically Based Rendering available in the Unreal Engine 4x, the author came up with the following findings:

- Opaque materials are represented with excellent quality, although the reflections are not entirely accurate, as also admitted by Epic Games (Karis, 2013). The author reached to the same conclusion while creating wood material using texture from the photo shooting and their photorealistic representation in the Unreal Engine.
- The tests with the glass ornaments of the couches showed that refractive materials, like glass are not represented well enough in comparison to the offline raytrace renderers. As discovered by the author after conducting thorough research online, this appears to be a common problem in all game engines, because they use forward or deferred rendering methods (the Unreal Engine 4 uses multi-tile deferred rendering). These methods are far inferior in rendering refractive materials than raytrace rendering methods, yet faster in rendering, a quite important asset in real-time performance.
- The tests run by the author showed that the representation of lighting and global illumination of the lightmass component can represent photorealistic results following the appopriate configuration (Epic Games c, n.d.; Epic Games d, n.d.;Epic Games a, n.d). As discovered following the experiments with the project, the lightmass rendered the entire scene in production quality within 6h17m, approximately double the time needed for a raytrace rendered with global illumination for a similar case. Render with Vray was complete within 2h51m. This duration is very sufficient for a game engine renderer, because in the next step the rendering result is saved in lightmap textures, not requiring rendering in real-time.

10. Conclusions and recommendations

By delving into this project and this project, the author proved that it is now possible to have photorealistic rendering in real-time applications thanks to the Physically Based Rendering (PBR) technology, which is integrated in the next generation game engines. The interactivity offered by these game engines and also the fact that most of them are VR ready, make them ideal for the creation of photorealistic virtual reality.

The dilemma “photo-realistic or real-time” is outdated; technology allows us to have them both.

Archaeology, aiming at reconstructing an image of the past is the perfect field to develop virtual reality projects. These projects, through the two aspects of the science of archaeology, humanistic and historical, are also right for education. At the same time, they contribute to the preservation and promotion of the world’s cultural heritage.

The development of an archaeological virtual reality project demands time, research, abilities, technical and artistic skills. In order to acquire these skills, a person needs to devote time and practice and this is the main reason why we find them in experienced 3d artists, who work with sophisticated software and advanced workflows. On the other hand, scientific documentation is the archaeologists’ field of expertise, following research and knowledge. Archaeological virtual reality is the convergence point between these completely different areas of expertise. It is the means allowing both archaeologists and creative media artists to work together and reconstruct the past. The exemplary cooperation in this project between the organizations, the consultants and the author is a manifestation of the fact that cooperation is possible and beneficial for both sides.

An archaeological virtual reality like the one of the House of the Mosaics places us into history, it allows us to take a walk into the original space, it transfers us back to antiquity. By taking this tour, the time traveller has the opportunity to form a more accurate and documented opinion about the aesthetics and daily life. The archaeologists can check their theories and also experience the mood of the space in its entirety, which they had previously just imagined and now can see it take shape before their eyes.

The application created through this project can also be used for educational purposes. It can work as an example for the type of andron of Hellenistic years. In this way, visitors of all ages and educational background will have the opportunity to understand how an andron may have been and compare it with modern dining rooms.

Real-time photorealistic rendering made virtual reality possible, which by its nature is a perfect educational means, as it doesn’t merely describe things, but it rather helps you experiencing them. Today, for the first time since the age of Plato who first coined the concept of virtual reality, we are in the position to implement it. Plato in his Allegory of the Cave used it as a negative example for the human nature in regard to education and ignorance. For us, it can be a springboard towards new positive educational methods.

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DIGITIZATION AND GAMIFICATION TECHNOLOGIES IN THE DESIGN, DEVELOPMENT AND EVALUATION OF A CULTURAL EDUCATIONAL PROGRAM FOR GREEK ART AND CULTURE

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Περίληψη

Στόχος της παρούσας εργασίας είναι η χρήση καινοτόμων τεχνολογιών για τη δημιουργία ενός εκπαιδευτικού προγράμματος διδασκαλίας της ελληνικής τέχνης και του πολιτισμού από την αρχαιότητα έως σήμερα στα πλαίσια του διδακτικού αντικειμένου της Ιστορίας. Νέες τεχνολογίες ψηφιοποίησης, μακροπρόθεσμης απόθεσης, διαλειτουργικότητας - βάσει διεθνών προτύπων μεταδεδομένων, επαυξημένης ή/και μεικτής πραγματικότητας, παιχνιδοποίησης και σοβαρών παιγνίων θα χρησιμοποιηθούν για την υποστήριξη της διδασκαλίας, ώστε να καταστεί πιο ελκυστική και αποτελεσματική για τους μαθητές. Η λογική αξιοποίησης και ένταξης των μαθητικών εμπειριών παιχνιδιού στο περιεχόμενο της επίσημης εκπαίδευσης στοχεύει στη δημιουργία κινήτρων, στη διευκόλυνση της μάθησης και ακόμα στην αλλαγή της στάσης των μαθητών απέναντι στο μάθημα της Ιστορίας. Το εκπαιδευτικό πρόγραμμα θα εφαρμοσθεί για λόγους αξιολόγησης και ανατροφοδότησης σε πραγματικές συνθήκες διδασκαλίας στη Δευτεροβάθμια Εκπαίδευση. Τα κριτήρια για την αξιολόγηση της διδασκαλίας: ψυχολογική ανταπόκριση των μαθητών, μαθητικά επιτεύγματα και χρηστικότητα του εκπαιδευτικού εργαλείου- θα αναδείξουν τα πλεονεκτήματα και τις αδυναμίες του εγχειρήματος για βελτιώσεις και μελλοντική έρευνα.

Abstract

The present study aims at the use of innovative technologies for the creation of a secondary educational program for teaching Greek art and culture, from the ancient years’ time to the present, as part of the school subject of “History”. New technologies such as digitization, long-term digital preservation, interoperability based on international metadata standards and augmented or/and mixed reality, gamification, and serious games will be used to support teaching, in terms of becoming more attractive and effective for students. The use of pupils' game experiences in the context of formal education aims to create incentives, facilitate learning, and even change students’ behavior towards the subject of “History”. The educational program, which is to be designed to meet the learning needs of both Secondary and High school students, will be applied for evaluation and feedback in real classroom teaching conditions. The evaluation of the program, which will be based on the students' psychological response, the identification of the students’ achievements and its user-friendliness as an educational tool, will help to highlight both its advantages and weaknesses for future research and improvement.

Λέξεις Κλειδιά/Keywords: Augmented Reality, Gamification, Didactic Scenario, Evaluation

1. Introduction

One of the most preferable leisure activities that constitutes and even determines young people’s social and cultural behavior is playing computer games (Fromme 2003). A number of studies for education have highlighted the role of computer games in developing a learning environment where students of all educational levels achieve better school results in an efficient, effective and entertaining manner (Vlachopoulos & Agoritsa M. 2017).

Computer game-based learning compared to traditional methods combines students’ game experiences with learning objectives and is therefore harmonized with their needs and fields of interest. Aspects of games such as competition, rewards, feedback, and selection of strategies, goal achievement and challenge conditions are supreme learning tools that enrich teaching procedure leading to impressive educational outcomes (Michala & Tsolis 2017). Some pedagogical benefits of computer games mentioned in literature reviews include: students’ engagement and motivation, active learning, faster school material understanding, long-term knowledge retention, improvement of school performance and opportunities for collaboration (Ke 2008, Gros 2007).

The implementation of computer games in education, however, may confront significant barriers coming from teachers' eagerness to be trained in new teaching methods and develop computer skills, parents' attitude towards the expansion of computer applications at school, and school administration that will provide technical support, equipment supplement and be in favor of innovative practices. Other obstacles may involve inflexibility of school curriculum, limited budget, negative effects of gaming, students' unreadiness and lack of supporting material (Arias 2014).

2. New Technologies in Education

Several studies worldwide have focused on the use of digital applications for educational purposes (e.g. Rosas et al. 2003, Squire et al. 2004, Virvou et al. 2005, Bottino & Ott 2006, Tan & Biswas 2007 cited in Michala et al. 2018). Considering the results it is obvious that computer and mobile gaming technologies have a strong impact on the students' mental and emotional ability. Students develop cognitive skills, adopt socially acceptable behavioural patterns and reproduce predominant cultural values and ideals of the society (Eichenbaum et al. 2014, Modafferi et al. 2016, Wang & Singhal 2016).

Gaming technologies in education involve the use of gamification tools that support digitization processes for educational purposes. Digitization enables the production of data making them available in applications. Consequently, the produced digital resources can be used by means of new technologies. Computer and mobile games enriched with virtual and augmented reality features can be used for game-based learning in various classroom lessons of all educational levels. *Second life* is an example of a learning platform with augmented reality features that could enhance students' gamification experiences (Michala & Tsolis 2018)

2a Gamification

Gamification refers to the use of gaming technologies in non-game situations in order to modify people's behaviors and enhance their commitment. As an educational approach gamification aims to motivate students' learning with the incorporation of game elements and the design of video games in learning environments. Gamification can, therefore, transform the school experience by helping teachers manage, motivate, and engage their students (Hamari et al. 2014).

Game techniques and strategies such as bonus – malus, credits, actions resulting to awards, feedback, new features in the same games (levels, add-ons, surprises) enhance the motivation, dedication, action effectiveness and affect the opinion of the pupils about a course positively.

Serious games and gamified educational software used in everyday teaching have benefits in the cognitive, emotional and social skills of the pupils. Focusing on the cognitive field, the complexity of the games' rules and the combination of exploration, experimentation and discovery lead to advanced mental skills. Actions and tasks in the gamified environment motivate students, and give them the initiative to select and correct actions so as to achieve goals and complete the game.

Regarding the emotional sector, games have strong benefits to pupils such as curiosity, enthusiasm, optimism and self-confidence. Failure, in most of cases is transformed to persistence, which has a great pedagogical value in life and education. Games create an environment where the effort, persistence and confidence is rewarded.

In the social field, finally, the possibility of taking different roles allows students to impersonate characters that they would not be able to experience in reality (Lee 2011).

2b Augmented Reality

Augmented Reality (AR) enables the real world to be combined or enhanced with digital objects and information. As a result, digital objects give the impression that coexist in the same space as the real ones (Azuma et al. 2011). The technology of AR offers an interactive learning environment where the students have the flexibility to move around and exploit digital information on the mobile device.

The current research proves a number of benefits by exploiting AR in formal education. The most important benefits are learning benefits, the extra curriculum motivation, collaborative interactive learning, and knowledge discovery, positive opinion for a course, enthusiasm, constructivism, perception of space and time (Hamari et al. 2016).

3. Didactic Scenario

The following teaching scenario is based on the idea of gamification. It refers to the Cycladic civilization (3000 / 2800 - 1450 BC) at prehistoric times and is designed for 1st grade secondary school students (Middle High School) in the Greek educational system. The didactic scenario is expanded in three didactic hours and requires portable PCs or else it can be held at school's computer laboratory.

The lesson plan is divided in three main sections. Initially, the educational goals are determined and classified into four categories: general, cognitive, digital literacy, and pedagogical. Secondly, the didactic scenario is developed, so as to fulfill the teaching goals set before. Finally, the evaluation system is designed, which will help to measure the learning outcomes and assess the teaching methodology as a whole.

3a Scenario Development

For the conduction of the lesson in the classroom students are divided into teams of 3-4 members. Each group receives a different worksheet by the teacher and browses the internet to explore the information required and complete their tasks. The worksheets designed correspond to the teaching objectives set by the teacher in the lesson plan. The tasks include the collection of information, images, photographs and maps about various aspects of the Cycladic civilization, virtual tours of museums' exhibition rooms and galleries, and creative activities using gamified digital applications as educational tools (e.g. tagxedo, mapmaker, flipsnack, cmaptools, canva/ glogster, hp photo creations, imagequilts, toondoo, animoto) in order to promote a game-like experience in the learning environment.

Once all groups have fulfilled their tasks, they gather with the other groups and the teacher to present their findings, show their creative activities, discuss and ask questions, exchange thoughts and emotions about the lesson with other groups. The teacher provides students with feedback, assesses the teamwork and each student's contribution to the group. Finally, groups vote for the best creative activity that will be uploaded on the official school website. The reward, which is a game element, creates the culture of compelling teams and encourages them to work harder to achieve their goals.

3b Evaluation System

The final part of the lesson is dedicated to the evaluation of the didactic scenario. The evaluation methods recommended are observation and questionnaire. Observational data can be obtained by the teacher during the lesson while students work, interact with each other and respond to the tasks assigned. The teacher observes both verbal and non-verbal behaviors that reveal the students' mental and emotional state towards the tasks, the lesson, the procedure, the teacher and other teams.

Questionnaires, on the other hand, make it possible to receive self-reported data. Students assess their own thoughts, emotions, behaviors and dynamic of relations between the members of the group. The teacher can, therefore, evaluate the accomplishment of the pre-set goals and reach conclusions about the success potential of the teaching methodology. Analyzing the results of the data collected the teacher can proceed to modifications, corrections and improvements of the teaching method, the tasks, the dynamic of groups and so on.

4. Discussion

In this paper we presented a didactic scenario for the Cycladic civilization in the Bronze Age that is addressed to students of lower secondary school. The idea is based on game-based learning where the learning environment is being enriched with game elements. According to the results of the current researches gamification is an educational approach that can enhance learning creating positive emotions of enthusiasm, excitement and self-confidence to students. What is more, gamification can promote collaborative learning and reinforce the relations between students. Finally, gamification provides the teacher with educational tools that facilitate the teaching procedure and engage the students in the learning process.

Compared to other traditional teaching methodologies that are teacher-centered and are based on the teachers' authority, which stems from their proficiency on the subject matter, the proposed didactic scenario eliminates the dominant role of the teacher emphasizing on the learner. Therefore, students do not count on the teacher's expertise and ability to offer and transfer school knowledge. Instead they are taught to discover the information on their own, navigating the internet, searching the information resources and selecting the material required. Consequently, the learning experience becomes more attractive since students use active ways to guide themselves in gaining knowledge, thus they achieve better learning outcomes.

Another advantage of the proposed teaching method is the use of new technologies. The didactic scenario combines good knowledge of the subject material with current technological advances in education. This way, the learning objectives are expanded including the development of both cognitive and digital skills. Accordingly, the teaching method is being modernized corresponding to the general demands of the technological revolution in education. Plus, students feel school harmonized to their needs and interests and are more willing to engage in the learning process.

What is more, a strong pros of the didactic scenario are the game elements incorporated in the teaching procedure. Many researchers stress that school does not take into account youngsters' inner need for entertainment, which can have a serious impact on learning. Gamification approaches through digital educational applications motivate students to participate in the lesson because they are really interested in it. Students' develop positive feelings of enthusiasm and curiosity that influence their general attitude towards the subject and learn faster.

Furthermore, creative activities that aim to relax students and give them opportunities to develop or cultivate talents have an important pedagogical value for students to discover other aspects of their personality and feel self-confident for their own original pieces of work. It is quite essential for the educational system to promote adolescents' creative skills along with the typical qualifications, in order to prepare them for the challenging working conditions in future career options and professional rehabilitation.

In conclusion, the didactic scenario described above is intended to offer a sample of a teaching methodology enriched with computer-game elements. On the next stage of the research, gamified techniques and AR features are to be used for the development of a digital application for the subject of History in Secondary Education, designed so as to constitute an educational tool assistant to the teacher in formal school.

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ΠΑΡΟΥΣΙΑΣΗ & ΑΝΑΛΥΣΗ ΤΗΣ ΗΛΕΚΤΡΟΝΙΚΗΣ ΠΑΡΟΥΣΙΑΣ ΤΩΝ ΕΡΓΑΣΤΗΡΙΩΝ ΣΥΝΤΗΡΗΣΗΣ ΕΡΓΩΝ ΤΕΧΝΗΣ & ΑΡΧΑΙΟΤΗΤΩΝ ΤΩΝ ΜΟΥΣΕΙΩΝ

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Περίληψη

Η ιστοσελίδα ενός μουσείου είναι 'ο χάρτης' των συλλογών των αντικειμένων όπως και άλλες λειτουργίες του για το ευρύ κοινό. Για τους περισσότερους το μουσείο έχει συνδεθεί με την παρουσίαση των εκθεμάτων και ως εκ τούτου οι σχετικές ιστοσελίδες κυρίως επικεντρώνονται σε αυτή τη λειτουργία του μουσείου. Όμως, εκτός από την έκθεση, σε ένα μουσείο επιτελούνται σημαντικές εργασίες, που τις περισσότερες φορές παραβλέπονται από το κοινό. Τέτοιου είδους εργασίες εκτελούνται στο πλαίσιο ενός εργαστηρίου συντήρησης έργων τέχνης & αρχαιοτήτων μέσα σε ένα μουσειακό περιβάλλον. Η ηλεκτρονική παρουσία όμως των εργαστηρίων συντήρησης των μουσείων συχνά παραμελείται με αποτέλεσμα να αγνοείται ή να υποβαθμίζεται στη συνείδηση του κοινού το σημαντικό έργο που επιτελεί η διατήρηση των συλλογών. Σε αυτή την εργασία γίνεται ανάλυση σε τριάντα (30) ιστοσελίδες σημαντικών εργαστηρίων συντήρησης όπου ανήκουν σε Μουσεία στο εξωτερικό και στον ελλαδικό χώρο, με έμφαση στο περιεχόμενο, την χρηστικότητα της ιστοσελίδας, την ευκολία πρόσβασης από την αρχική σελίδα του μουσείου, τα πολυμέσα που χρησιμοποιούνται, το περιβάλλον διεπαφής, κ.ά. Τα αποτελέσματα παρουσιάζουν ότι ορισμένα μουσεία έχουν επενδύσει στην ηλεκτρονική παρουσία των εργαστηρίων συντήρησης, δείχνοντας σημαντικά προγράμματα συντήρησης εκθεμάτων (case studies), προωθώντας τη συντήρηση ή την προληπτική συντήρηση ως επιστήμη και υποστηρίζοντας γενικότερα τη διάχυση της γνώσης στο ευρύ κοινό.

Abstract

A museum's website is the 'map' of objects collections, as well as other functions for the general public. Therefore, the museum has been linked mainly within the public with their exhibit artefacts, for this reason relevant websites are mainly focused on this museum function. However, in addition to the exhibition, a major work is being done in a museum environment, which is often overlooked by the public. Such works are carried out within a conservation lab for the within a museum environment. The electronic presence of museum conservation labs is often neglected as a result of ignoring or diminishing the public's consciousness of the important work of preserving collections. In this work, a web site analysis of thirty (30) museum conservation labs around the world is carried out, focusing on the content, usability of the website, ease of access from the museum homepage, media used, the interface, etc. Therefore, the results show that some museums have invested in the online presence of the conservation labs, showing significant conservation case studies, promoting conservation or preventive conservation as a science and generally supporting the diffusion of knowledge to the general public.

Λέξεις Κλειδιά/Keywords: εργαστήρια συντήρησης, συντήρηση, ιστοσελίδες, μουσεία/conservation labs, conservation, websites, museums

1. Εισαγωγή

Η ιστοσελίδα ενός μουσείου είναι 'ο χάρτης' των συλλογών των αντικειμένων όπως και άλλες λειτουργίες του για το ευρύ κοινό. Για τους περισσότερους το μουσείο έχει συνδεθεί με την παρουσίαση των εκθεμάτων και ως εκ τούτου οι σχετικές ιστοσελίδες κυρίως επικεντρώνονται σε αυτή τη λειτουργία του μουσείου. Όμως, εκτός από την έκθεση, σε ένα μουσείο επιτελούνται σημαντικές εργασίες, που τις περισσότερες φορές παραβλέπονται από το κοινό. Τέτοιου είδους εργασίες εκτελούνται στο πλαίσιο ενός εργαστηρίου συντήρησης έργων τέχνης & αρχαιοτήτων μέσα σε ένα μουσειακό περιβάλλον. Η ηλεκτρονική παρουσία όμως των εργαστηρίων συντήρησης των μουσείων συχνά παραμελείται με αποτέλεσμα να αγνοείται ή να υποβαθμίζεται στη συνείδηση του κοινού το σημαντικό έργο που επιτελεί η διατήρηση των συλλογών.

Παρόλα αυτά, η ηλεκτρονική παρουσία ενός μουσείου ή ενός εργαστηρίου συντήρησης δεν αρκεί για την επιτυχία τους και την προσέλκυση των κοινού. Οι ερευνητές τονίζουν ότι οι ιστοσελίδες αυτές πρέπει να είναι εύκολα προσβάσιμες και χρηστικές (Dyson & Moran 2000). Επιπροσθέτως πολλοί ερευνητές έχουν τονίσει την ανάγκη για την αξιολόγηση των ηλεκτρονικών μουσείων ώστε να καλύπτουν τις βασικές απαιτήσεις (π.χ. Cunliffe *et al*. 2001, Welie & Klaasse 2004, Kabassi 2017, Kabassi & Martinis 2017).

Στην παρούσα εργασία γίνεται ανάλυση σε τριάντα (30) ιστοσελίδες σημαντικών εργαστηρίων συντήρησης που ανήκουν σε Μουσεία ανά τον κόσμο, με έμφαση στο περιεχόμενο, την χρηστικότητα της ιστοσελίδας, την ευκολία πρόσβασης από την αρχική σελίδα του μουσείου, τα πολυμέσα που χρησιμοποιούνται, το περιβάλλον διεπαφής, κ.ά.

Για την ανάλυση των ιστοσελίδων χρησιμοποιήθηκε μια μέθοδος επιθεώρησης. Στις μεθόδους επιθεώρησης, η αξιολόγηση γίνεται από έμπειρους χρήστες. Πολλοί ερευνητές έχουν επιχειρηματολογήσει θετικά για τις μεθόδους επιθεώρησης λέγοντας ότι είναι πιο εύκολες και πιο φθηνές σε σχέση με τις εμπειρικές μεθόδους (Reeves 1993, Karoulis *et al*. 2006).

Το κυρίως μέρος του άρθρου οργανώνεται ως ακολούθως: Η ενότητα 1 περιγράφει την επιλογή των ιστοσελίδων. Η ενότητα 2 παρουσιάζει το πολυκριτήριο μοντέλο που θα χρησιμοποιηθεί και τη διαδικασία ανάλυσης των ιστοσελίδων των εργαστηρίων συντήρησης μουσείων. Στην ενότητα 3 παρουσιάζονται τα αποτελέσματα της πολυκριτήριας ανάλυσης. Η ενότητα 4 παρουσιάζει μια μικρή ανάλυσης των αποτελεσμάτων, παρουσιάζοντας τις ιστοσελίδες που έχουν ταξινομηθεί ως καλύτερη και χειρότερη. Τέλος, στην τελευταία ενότητα παρουσιάζονται τα συμπεράσματα που εξήχθησαν από αυτή τη διαδικασία.

2. Επιλογή ιστοσελίδων

Η επιλογή των προς αξιολόγηση ιστοσελίδων, έγινε μέσω της εμφάνισής τους σε μηχανές αναζήτησης (Google® search) αναγράφοντας σχετικές λέξεις – κλειδιά όπως «εργαστήριο συντήρησης» ή «museum conservation laboratory», δηλαδή με το κατά πόσο μπορούν να εντοπιστούν σε μια σχετική αναζήτηση ενός διαδικτυακού χρήστη.

Τα εργαστήρια συντήρησης που επιλέχθηκαν από αυτή τη διαδικασία ανήκουν στα παρακάτω Μουσεία:

- Αρχαιολογικό Μουσείο Θεσσαλονίκης
- Βυζαντινό και Χριστιανικό Μουσείο Αθηνών
- Μουσείου Μπενάκη
- Εθνικής Πινακοθήκης & Μουσείο Αλέξ. Σούτσου
- Μουσείο Βυζαντινού Πολιτισμού Θεσσαλονίκης
- Guggenheim Museum
- Metropolitan Museum
- Smithsonian Museum Conservation Institute
- The Getty Foundation
- NTNU University Museum
- Boston Museum of Fine Arts
- University of Michigan Museum of Art Conservation Lab
- Conservation Laboratory of the Oriental Institute Museum
- MoMa’s Conservation Department
- Brooklyn Museum
- De Young museum of Fine Arts
- Victoria & Albert Museum, UK
- Tate Modern, UK
- The British Museum
- National Museum New Delhi
- Vatican Museums
- Hermitage Museum
- Museum of Islamic Art – Doha
- Australian museum
- Museo Del Prado Madrid
- Galleria Nazionale d'Arte Moderna
- Barberini – Corsini Gallery
- Rijksmuseum
- Tokyo National Museum
- Whitney Museum of American Art

Η ανάλυση που έγινε αφορούσε κυρίως στο περιεχόμενο και σε βασικά στοιχεία δομής και εμφάνισης των ιστοσελίδων.

3. Ανάλυση ιστοσελίδων βάσει κριτηρίων

Οι Kabassi *et al*. 2018, διενέργησαν μια μελέτη στην οποία συμμετείχαν επαγγελματίες συντηρητές έργων τέχνης & αρχαιοτήτων. Οι συντηρητές αυτοί ερωτήθηκαν σχετικά με τα κριτήρια που χρησιμοποιούν όταν αξιολογούν ιστοσελίδες σχετικές με συντήρηση. Τα αποτελέσματα έδειξαν ότι οι συντηρητές εστιάζουν κυρίως στο περιεχόμενο της ιστοσελίδας. Καταλήγοντας, ορίζουν ότι τα κριτήρια που λαμβάνονται υπόψη από τους συντηρητές καθώς αξιολογούν μια σχετική ιστοσελίδα είναι τα παρακάτω:

C1: Περιεχόμενο για το προσωπικό

C2: Περιεχόμενο για τον εξοπλισμό
C3: Περιεχόμενο για τα ερευνητικά προγράμματα
C4: Επικαιροποίηση
C5: Προσβασιμότητα
C6: Πολυμέσα
C7: Πληρότητα
C8: Χρηστικότητα/Περιβάλλον διεπαφής

Στο ίδιο πείραμα (Kabassi *et al*. 2018) ορίστηκαν και τα βάρη αυτών των κριτηρίων ως ακολούθως: w_{C1}=0.083, w_{C2}=0.083, w_{C3}=0.083, w_{C4}=0.144, w_{C5}=0.183, w_{C6}=0.122, w_{C7}=0.150, w_{C8}=0.150.

Οι τρεις ειδικοί έκαναν ένα περιδιάβασμα των ιστοσελίδων των εργαστηρίων συντήρησης των μουσείων. Μετά από αυτή τη διαδικασία, του ζητήθηκε να δώσουν ένα βαθμό σε καθένα από τα κριτήρια C1-C8 για κάθε ιστοσελίδα. Για παράδειγμα, ένας συντηρητής έδωσε την παρακάτω βαθμολογία στην ιστοσελίδα του εργαστηρίου συντήρησης του Μητροπολιτικού Μουσείου C1=5, C2=5, C3=5, C4=4, C5=2, C6=3, C7=3, C8=3.
Αυτή η διαδικασία οδήγησε στη δημιουργία τριών πινάκων όπου οι γραμμές είναι τα κριτήρια και στήλες τα μουσεία. Οι τρεις πίνακες ενώθηκαν σε ένα χρησιμοποιώντας το γεωμετρικό μέσο των τριών αξιολογητών. Για το συνδυασμό όλων των κριτηρίων και την παραγωγή μιας τιμής για κάθε ιστοσελίδα ώστε να προκύψει μια κατάταξη χρησιμοποιήθηκε μια πολυκριτήρια θεωρία λήψης αποφάσεων.

Υπάρχουν πολλές πολυκριτήριες θεωρίες που υπολογίζουν μία τιμή για κάθε εναλλακτική προκειμένου να δημιουργηθεί μια τελική κατάταξη. Μία αρκετά απλή και δημοφιλής μέθοδος είναι το Απλό Σταθμισμένο Άθροισμα (Simple Additive Weighting - ΑΣΑ) (Fishburn 1967, Hwang & Yoon 1981).

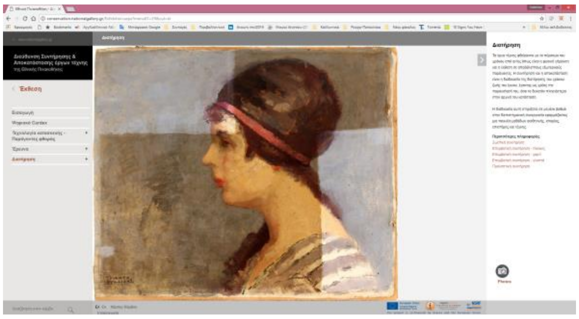
Η μέθοδος του Απλού Σταθμισμένου Αθροίσματος είναι πιθανότατα η πιο γνωστή και ευρέως χρησιμοποιούμενη μέθοδος και αποτελείται από δύο βασικά στάδια:

1. **Διαμόρφωση των τιμών των n κριτηρίων ώστε να γίνουν συγκρίσιμα**. Υπάρχει περίπτωση μερικά κριτήρια να λαμβάνουν ακέραιες τιμές στο [0,10000] ενώ μερικά άλλα δεκαδικές στο [0,1]. Η διαμόρφωση τιμών πρέπει να γίνεται με τέτοιο τρόπο ώστε όλα τα κριτήρια να λαμβάνουν τις τιμές τους στο ίδιο διάστημα.
2. **Άθροισμα όλων των τιμών των n κριτηρίων για κάθε εναλλακτική περίπτωση**. Η τιμή της πολυκριτήριας συνάρτησης υπολογίζεται για κάθε εναλλακτική ως ένας γραμμικός συνδυασμός των n κριτηρίων.

Η μέθοδος ΑΣΑ μεταφράζει ένα πρόβλημα απόφασης στη βελτιστοποίηση μιας συνάρτησης U που ορίζεται στο A. Ο λήπτης αποφάσεων υπολογίζει τη συνάρτηση $U(X_j)$ για κάθε εναλλακτική περίπτωση Xj και επιλέγει αυτή με τη μεγαλύτερη τιμή. Η συνάρτηση U υπολογίζεται ως ένας γραμμικός συνδυασμός των κριτηρίων και δίδεται από τον παρακάτω τύπο:

$$U(X_j) = \sum_{i=1}^{n} w_i x_{ij}, \qquad (5.2)$$

όπου *Xj* είναι μια εναλλακτική και *xij* είναι η τιμή του κριτηρίου *i* για την εναλλακτική *Xj*.



Εικόνα 1. Η ιστοσελίδα της Διεύθυνσης Συντήρησης της Εθνικής Πινακοθήκης & Μουσείο Αλέξ. Σούτσου, Αθήνα.

4. Αποτελέσματα

Ο υπολογισμός της τιμής $U(X_j)$ για κάθε εναλλακτική ιστοσελίδα παρουσιάζεται στον πίνακα I.

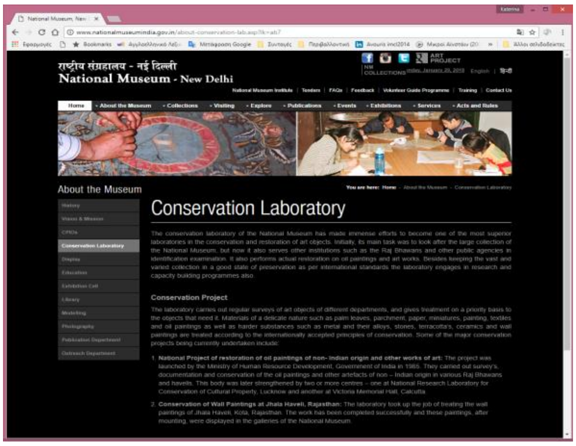
ΑΑ	Ιστοσελίδα	ΑΣΑ
1	Διεύθυνση Συντήρησης-Εθνικής Πινακοθήκης & Μουσείο Αλέξ. Σούτσου	4.187
2	Boston Museum of Fine Arts	3.936
3	Guggenheim Museum	3.775
4	Whitney Museum of American Art	3.67
5	Vatican Museum	3.521
6	Metropolitan Museum	3.453
7	Hermitage Museum	3.449
8	British Museum	3.204
9	MoMa	3.166
10	Smithsonian museum	3.165
11	Μουσείο Μπενάκη	3.144
12	Victoria & Albert Museum	3.144
13	Tate Modern	3.144

14	Museo Del Prado	3.039
15	Australian Museum	3.027
16	Βυζαντινό & Χριστιανικό Μουσείο, Αθηνών	3.011
17	Brooklyn museum	2.888
18	Μουσείο Βυζαντινού Πολιτισμού Θεσσαλονίκης	2.861
19	Αρχαιολογικό Μουσείο Θεσσαλονίκης	2.761
20	Oriental Institute Museum	2.684
21	Rijksmuseum	2.462
22	De Young museum of Fine Arts	2.435
23	Tokyo National Museum	2.285
24	Barberini – Corsini Gallery – Roma	2.241
25	Getty Foundation	2.201
26	University of Michigan Museum of Art	2.08
27	Museum of Islamic Art – Doha	1.93
28	NTNU University Museum	1.813
29	Galleria Nazionale d'Arte Moderna	1.786
30	National Museum New Delhi	1.741

Πίνακας 2. Κατάταξη των ιστοσελίδων των εργαστηρίων συντήρησης σε μουσεία.

5. Ανάλυση αποτελεσμάτων

Καλύτερες ιστοσελίδες στον ελλαδικό χώρο ήταν τα εργαστήρια συντήρησης της Εθνικής Πινακοθήκης & Μουσείο Αλεξ. Σούτσου και στο εξωτερικό το Μουσείο Τεχνών της Βοστόνης. Πράγματι, η ιστοσελίδα της Εθνικής Πινακοθήκης ήταν ιδιαίτερα αναλυτική, με μεγάλο όγκο διαθέσιμων πληροφοριών για τις δραστηριότητες του τμήματος και σημαντική υποστήριξή τους με μεγάλο αριθμό πολυμέσων (φωτογραφίες, βίντεο). Ο ιστότοπος αυτός χωρίζεται σε πολλές ξεχωριστές σελίδες με πληροφορίες για κάθε μια από τις δραστηριότητες που αφορούν, είτε τα ξεχωριστά εργαστήρια ανά είδος υλικού, είτε τα διάφορα είδη επεμβατικής ή μη συντήρησης, είτε την έρευνα, ακόμα και τον ενεργό εκπαιδευτικό ρόλο για τη διάδοση της επιστήμης της συντήρησης και τη γενικότερη διάχυση της γνώσης. Υπάρχει επίσης αναλυτική περιγραφή και παρουσίαση του προηγμένου και άρτιου εξοπλισμού του εργαστηρίου στα πλαίσια των πρακτικών συντήρησης και των περιπτώσεων που συνδέονται με τη χρήση του. Οι εργαζόμενοι του τμήματος αναφέρονται ονομαστικά ανάλογα με το ρόλο τους και διαθέτουν επίσης στοιχεία επικοινωνίας. Η πρόσβαση στη σελίδα από τον κεντρικό ιστότοπο του μουσείου είναι ιδιαίτερα εύκολη, με απευθείας σύνδεσμο από την αρχική σελίδα. Έχει πρωτότυπη και ελκυστική αισθητική, είναι εύχρηστη και με προσεγμένη δομή και οργάνωση. Αναμφίβολα η καλύτερη σελίδα για τα ελληνικά δεδομένα και από τις καλύτερες διεθνώς.



Εικόνα 1. Ιστοσελίδα εργαστηρίου συντήρησης του Εθνικού Μουσείου στο Νέο Δελχί (http://www.nationalmuseumindia.gov.in/about--conservation-lab.asp?lk=ab7)

Η ιστοσελίδα που συγκέντρωσε την μικρότερη βαθμολογία ήταν αυτή του εργαστηρίου συντήρησης του Εθνικού Μουσείου στο Νέο Δελχί. Το συγκεκριμένο εργαστήριο διαθέτει μια απλή στοιχειώδης σελίδα, με πολύ περιληπτικές πληροφορίες για το ρόλο και τις αρμοδιότητες του εργαστηρίου συντήρησης. Δεν διαθέτει καμία διαθέσιμη πληροφορία για τον εξοπλισμό και το προσωπικό του τμήματος. Περιληπτική αναφορά γίνεται σε δύο ολοκληρωμένα έργα στα οποία συμμετείχε το εργαστήριο συντήρησης ενώ γενικότερα η σελίδα δεν φαίνεται να είναι επικαιροποιημένη. Το περιβάλλον διεπαφής δεν είναι ιδιαίτερα χρηστικό και από πολυμέσα υπάρχουν μόνο ελάχιστες φωτογραφίες.

6. Συμπεράσματα

Ο στόχος της παρούσας εργασίας ήταν να αξιολογηθούν οι ιστοσελίδες των εργαστηρίων συντήρησης έργων τέχνης & αρχαιοτήτων Μουσείων με επιστημονικά τεκμηριωμένο και αντικειμενικό τρόπο και να τοποθετηθούν σε μια κατάταξη που να αναδεικνύει σε ποιο βαθμό επιτυγχάνουν να εκπληρώσουν τους σκοπούς της ύπαρξής τους ικανοποιώντας διεθνώς αναγνωρισμένα κριτήρια. Για την επίτευξη αυτού του στόχου διενεργήθηκε μια μελέτη των ιστοσελίδων από την οποία προέκυψαν βασικά συμπεράσματα γύρω από το περιεχόμενο τους.

Το περιεχόμενο κάθε ιστοσελίδας δομείται με στόχο να προσελκύσει κάποιους επισκέπτες. Το είδος (ή τα είδη) των επισκεπτών που ενδιαφέρεται να προσελκύσει κάθε ιστοσελίδα/ιστότοπος καθορίζει σε μεγάλο βαθμό τη δομή και το περιεχόμενό του. Αυτό πρέπει να είναι σαφές κατά το σχεδιασμό της ιστοσελίδας/ιστοτόπου, έτσι ώστε να επιτύχει κατά τον καλύτερο δυνατό το στόχο της. Από τις ιστοσελίδες αυτές, άλλες απευθύνονταν κυρίως στο γενικό κοινό, άλλες σε υποψήφιους χορηγούς-δωρητές και λιγότερες σε ειδικούς επιστήμονες (συντηρητές και φοιτητές τμημάτων συντήρησης). Ορισμένες κατάφερναν επιτυχώς να μπορούν να απευθύνονται σε περισσότερες κατηγορίες χρηστών με τον κατάλληλο σχεδιασμό, την ελκυστική εμφάνιση και τη σωστή οργάνωση του περιεχομένου τους.

Από αυτή την ανάλυση προέκυψε ότι όλες οι ιστοσελίδες είχαν τις βασικές απαραίτητες πληροφορίες για το ρόλο, το σκοπό και τις αρμοδιότητες του εργαστηρίου/τομέα συντήρησης του μουσείου.

Πολλές είχαν ελκυστικό περιβάλλον διεπαφής και συνόδευαν τις πληροφορίες τους με πολυμέσα όπως φωτογραφίες και βίντεο.

Αρκετές είχαν ενδιαφέρον περιεχόμενο, παρουσίαζαν συγκεκριμένα *projects* και παρείχαν ικανοποιητικό όγκο πληροφοριών για τις δραστηριότητές τους. Λίγες έδιναν πιο εξειδικευμένες πληροφορίες για το επιστημονικό προσωπικό, τον εξοπλισμό και συγκεκριμένες τεχνικές συντήρησης. Ελάχιστες από αυτές είχαν περιεχόμενο διαθέσιμο σε πάνω από δύο γλώσσες, ορισμένες δε ήταν διαθέσιμες μόνο σε μία γλώσσα.

Προκειμένου να συγκριθούν και να αξιολογηθούν οι τριάντα (30) ιστοσελίδες των εργαστηρίων συντήρησης όπου ανήκουν σε Μουσεία διενεργήθηκε μια νέα μελέτη όπου χρησιμοποιήθηκε μια μέθοδος επιθεώρησης σε συνδυασμό με μια πολυκριτήρια θεωρία, το Απλό Σταθμισμένο Άθροισμα. Από τη διαδικασία αυτή προέκυψε μια τελική κατάταξη των ιστοσελίδων.

Είναι στα μελλοντικά σχέδια των συγγραφέων να εξετάσουν και άλλα πολυκριτήρια μοντέλα για την αξιολόγηση των ιστοσελίδων των εργαστηρίων συντήρησης και να συγκρίνουν τα αποτελέσματα προκειμένου να εντοπίσουν ποιο ταιριάζει καλύτερα στη συγκεκριμένη περίπτωση.

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Session 6

Statistical / agent-based modelling

HIERARCHICAL CLASSIFICATION FOR IMPROVED COMPOUND IDENTIFICATION IN RAMAN SPECTROSCOPY

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Περίληψη

Στο παρόν άρθρο, δείχνουμε ότι με τη χρήση μιας καθιερωμένης ιεραρχικής μεθόδου σε ένα πλαίσιο εποπτευόμε-νης μάθησης επιτυγχάνουμε ανώτερες επιδόσεις όσον αφορά την ακρίβεια ανίχνευσης ορυκτών από τα φάσματα Raman με μειωμένο υπολογιστικό κόστος. Χρησιμοποιούμε τις εγγενείς ιεραρχικές ιδιότητες της μεθόδου με βά-ση τα δέντρα αποφάσεων για να δείξουμε ότι το προτεινόμενο μοντέλο είναι σε θέση να ταξινομήσει σωστά ορυ-κτά είδη στις αντίστοιχες ομάδες, τύπους και κατηγορίες χωρίς να επιβάλλει ρητά σύστημα πολλαπλών ετικετών κατά την εκπαίδευση του μοντέλου. Αξιολογήσαμε τη μέθοδο μας με το σύνολο δεδομένων αναφοράς RRUFF και διαπιστώσαμε ότι η μέθοδος μας ξεπέρασε τα καλύτερα αποτελέσματα των άλλων προσεγγίσεων κατά 4% στην ακρίβεια ταξινόμησης.

Abstract

In this paper, we show that with the use of a well-established hierarchical method in a supervised learning framework we achieve superior performance in terms of mineral identification accuracy from Raman spectra with reduced computational cost. We exploit the intrinsic hierarchical properties of the tree-based method to show that the proposed model is able to correctly classify mineral species into their respective mineral groups, types and classes without explicitly imposing a multi-label system during the model's training. We evaluated our method with the benchmark dataset RRUFF, and, overall, we found that our method outperforms the best re-sults of the other approaches by 4% in classification accuracy.

Λέξεις Κλειδιά/Keywords: Machine Learning, Hierarchical Classification, Extra Randomized Trees, Archaeometry, Raman Spectroscopy, Mineral Identification

1. Introduction

Analysis and interpretation of spectral information has been an active field of research for a long time. Applications of spectral analysis span a wide range of fields, such as planetary exploration, geological field expeditions, materials research, medical diagnosis, etc. In the field of Cultural Heritage, the identification of chemical compounds in artifacts is an important and challenging task that can contribute significant information towards the interpretation of the artifacts' past. Solutions for such a task can be based on spectroscopy and particularly, Raman spectroscopy, which is becoming a daily practice in archaeometry (Bersani & Madariaga 2012). Current practices rely heavily on the skills of the experts to identify the chemical compounds. Therefore, a method that is be able to achieve accurate identification results would be a valuable tool.

An effective approach to compound identification is the use of the entire spectral range for multivariate analysis. As previously was shown, full-spectrum matching algorithms e.g., pseudo-logarithmic histogram matching and vector similarity metrics exhibit sufficient performance in classification tasks, without requiring dimensionality reduction or model training. However, this has disadvantages since the lack of modelling yields poor discriminability when it comes to capturing the nuances of each spectrum, due to a sample's irregular chemical mixture, which ultimately leads to misclassifications.

In this paper, we show that with the use of a well-established hierarchical method in a supervised learning framework, namely extra randomized trees (Geurts *et al.* 2006), we achieve superior performance in terms of accuracy when compared with existing state of the art methods, without sacrificing computational speed. Furthermore, we exploit the intrinsic hierarchical properties of the tree-based method to show that the proposed model is able to correctly classify the mineral species into their respective mineral groups, types and classes, based on the Dana Classification Scheme (Gaines *et al.* 1997), without explicitly imposing a multi-label system during the model's training.

We evaluated our method with the benchmark dataset RRUFF (Lafuente *et al.* 2015), which provides a complete set of high quality spectral data from well characterized minerals. We compared extra randomized trees with the following methods:

(i) 1-nearest neighbor classifier, which CrystalSleuth's matching software is believed to be based upon (Carey *et al.* 2015, Bartholomew *et al.* 2015);
(ii) weighted neighbor (WN) classifier;
(iii) vector metric, the cosine similarity after normalization and squashing (Lafuente *et al.* 2015).

Overall, we found that our method outperforms the best results of the other approaches by 4% in species classification accuracy. Another important contribution of our work is that we exploited the inherent hierarchical properties of tree-based methods to classify the species to their respective types and groups according to the DANA mineral classification scheme. Therefore, Extra Randomized Trees is a method able to learn and discriminate efficiently the subtle discrepancies of the chemical mixtures in spectral samples without computational burden.

2. Raman spectra and mineral identification

Mineral identification with Raman Spectroscopy is an everyday practice in various domains. Just indicatively, Raman spectroscopy has been used with success in medicine (Bi *et al.* 2009), in the pharmaceutical industry (Kong *et al.* 2015), in planetary exploration (Mars 2020 Rover is equipped with SHERLOC, the Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals component)[1], and in cultural heritage (Madariaga 2015). However, commercial software solutions provide identification accuracy with an expected error of around 20% (Liu *et al.* 2017, Carey *et al.* 2015).

Expert knowledge of spectral features has been traditionally the driving force in spectra identification. Recent approaches made use of a variety of statistical and machine learning tools to overcome this limitation. Among the earliest works in the field was that of Mischna *et al.* (2003), which influenced works like the ones in automated mineral identification on ExoMars (Sobron et al. 2008, Lopez-Reyes *et al.* 2013, Lopez-Reyes *et al.* 2014). In addition, it was as early as 2004 that automated identification of minerals using univariate analysis has also been studied (Perez-Pueyo *et al.* 2004) with subsequent works building on the same track (Kriesten *et al.* 2008, Rodriguez *et al.* 2014), but the approach is not fully adaptable to mineral mixtures.

Early approaches focused on identifying specific components (Paradkar *et al.* 2002, Gilmore *et al.* 2008). Other approaches focused on clustering spectra into groups (Ishikawa & Gulick 2013, Roush & Hogan 2007). More recent approaches made wide use of Support Vector Machines (Suykens & Vandewalle 1999), a powerful machine learning tool that has been used for applications on mineral detection with near-infrared spectroscopy (Gilmore *et al.* 2008), as well as in composition prediction with Raman spectra (Thissen *et al.* 2004). Another machine learning approach with increasing use in spectroscopy is that of the Artificial Neural Networks (Roush & Hogan 2007, Gallagher & Deacon 2002). Other approaches included similarity-based methods (Sobron *et al.* 2008) or even full-spectrum matching methods (Bayraktar *et al.* 2013, Lowry *et al.* 2009).

In most cases pre-processing steps are being followed to address noise and fluorescence (Jaszczak 2013, Carron & Cox 2010). Since spectra are represented as high-dimensional feature vectors, projections onto lower-dimensional spaces have also been investigated, using typical approaches like principal components analysis (Baeten *et al.* 1998, Ishikawa & Gulick 2013).

In most of the studies the full RRUFF Raman dataset was used (Lafuente *et al.* 2015) as a benchmark reference set. The methods that were developed have been employed mainly to recognize a substance or a small group of the specimen's family. Most recent works focused on identifying mineral species in RRUFF, using nearest neighbor methods with different similarity metrics, such as cosine similarity and correlation. Carey *et al.* (2015) achieved a species classification accuracy on a subset of the RRUFF of 84.8\% using a Weighted Neighbor classifier, after applying data pre-processing (square root squashing, maximum intensity normalization, and sigmoid transformations). It was also reported that a k=1 Nearest Neighbor classifier achieved 82.1% accuracy. A number of methods has been tested, including k-NN, Decision Tree, Random Forest, Multilayer Perceptron, with different outcomes. Recently, Liu *et al.* (2017) created a Deep Convolutional Neural architecture for Raman spectra recognition and baseline correction and reported an accuracy of spectra recognition on the already baseline corrected data of 88.4%. They also reported achieving 93.3% accuracy on the raw data.

[1] Mars 2020 Rover SHERLOC @ https://mars.nasa.gov/mars2020/mission/instruments/sherloc/

3. The proposed method

In this work we propose the use a combination of a pre-processing and an off-the-shelf machine learning method to achieve high accuracy mineral identification on baseline corrected Raman spectra. The machine learning method of preference is a variant of Random Forest, the Extremely Randomized Tress (or simply Extra Trees) in the family of Ensemble Learning methods that is based on decision trees but gives a significant advantage in tackling overfitting issues. Many of the earlier works in the field suggested that tree-based methods are expected to perform poorly (Maguire *et al.* 2015, Carey *et al.* 2015, Liu *et al.* 2017). However, we propose a proper data pre-processing and augmentation, which results in rendering Random Forest methods particularly efficient in mineral identification.

Overall, the proposed method consists of

- Proper data pre-processing: this is a three-step process aiming to normalize the data and prepare for a more successful model learning
- Data augmentation for training: this is a process of producing artificial data to support the machine learning approach achieve generalized learning
- Model learning and mineral identification using ensemble learning approaches, namely Random Forest and Extra Trees

For a fair evaluation against previous works and to achieve the required repeatability in the experiments, the RRUFF dataset was selected for the experimental evaluation as this is an established benchmark dataset.

3a Data pre-processing

The motivation for the data pre-processing is illustrated in Fig. 1, which shows an example of two samples from the same family of species. Despite the differences in the peak-intensity values, these samples should be classified into the same species. Apparently, with data like these it is difficult for a machine learning method to easily and reliably learn a general model. Thus, the data need to be treated in a way that the samples from the same family of species become more obviously similar. Since the intensity (peak) in those data are irrelevant in the composition and identification, only the location of the peak is important, and consequently the peaks should be aligned and scaled appropriately.

There are several methods to achieve this kind of normalization. We were influenced by earlier successful works and we opted for the following data pre-processing steps:

- Square root transformation, $f(x) = \sqrt{x}$
- Intensity normalization, using the L_∞ norm, $|x|_\infty = \max(|x_i|)$
- Sigmoid transformation, using $f(x) = \frac{1-\cos \pi x}{2}$ with $(x, f(x) \in [0,1])$

For an intuition on what the square root and the sigmoid transformations do we illustrate their graphs in Fig. 2. The result of the application of these pre-processing steps on the samples in Fig. 1 are shown in Fig. 3.

3b Data augmentation

Typically, in machine learning applications, data augmentation should be applied in cases in which the training data volume is not enough for a successful training. Following the Raman spectra characteristics of possible horizontal shifting and the peak irrelevance in mineral identification, the adopted data augmentation strategy in this work included

- A random horizontal shifting of each spectrum for a few wavenumbers (maximum ± 5)
- The application of additive gaussian noise, proportional to the magnitude of the spectra, at each wavenumber (maximum 10% of the magnitude)

Fig. 4 shows an example of sample data augmentation, in which the color variation represents a slightly shifted noisy alternative to an original sample.

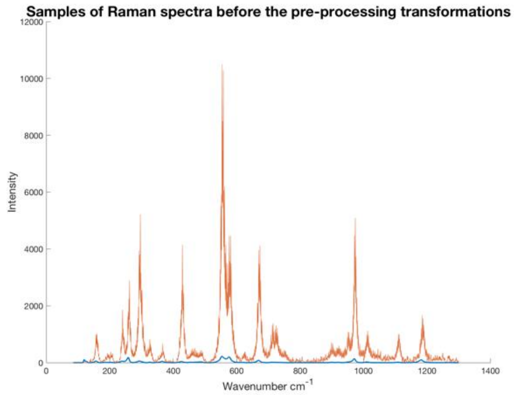

Figure 1. Example of samples that belong to the same family of species, despite the significant differences in the peak-intensity values.

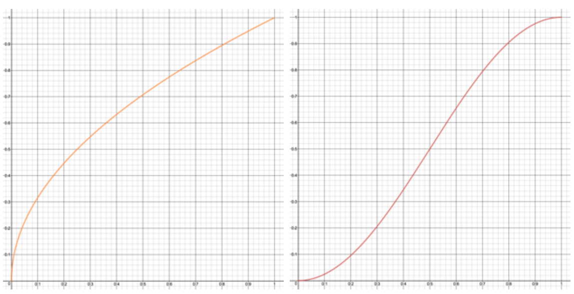

Figure 2. The square root and the sigmoid transformation in the interval [0,1].

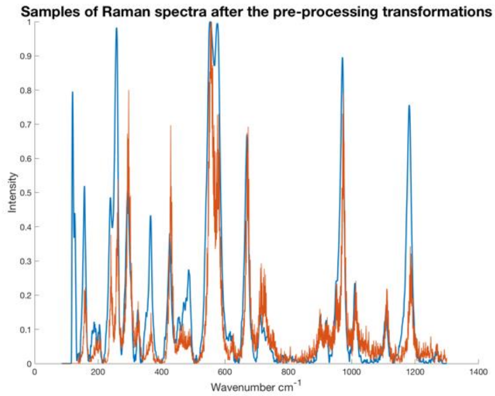

Figure 3. Samples after all pre-processing steps. The peak intensities are normalized and belong in the same range.

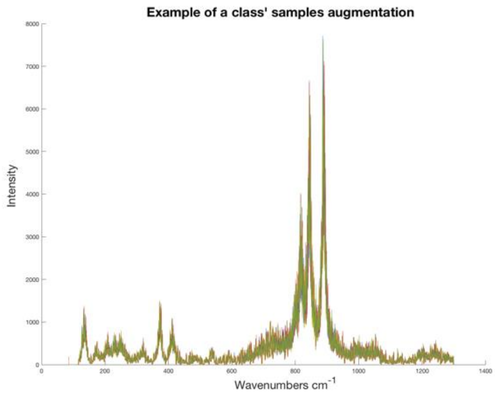

Figure 4. An example of sample data augmentation.

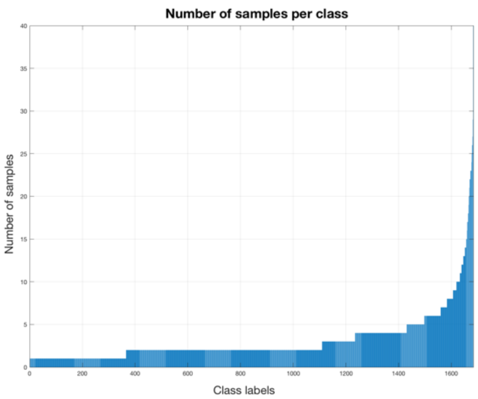

Figure 5 Statistical profile of the RRUFF dataset.

3.c Ensemble learning

Generally, Random Forest methods[2] (particularly the Extra Trees or Extremely Randomized Trees variation) are expected to be good model learners from data such as those representing Raman spectra, which are high dimensional signatures. Earlier work in the field suggested that Random Forest methods are not to be expected to be powerful enough for mineral identification tasks from Raman spectra. Nevertheless, our idea of including data pre-processing and augmentation significantly changes the picture as will be shown in the experimental results.

4. Experiments and evaluation

The RRUFF Project[3] is creating a complete set of high quality spectral data from well characterized minerals. It holds more than 5,000 samples publicly available, including metadata like the mineral name, a unique ID, the ideal chemical type, locality, ownership, source, description, status, and more. The statistical profile of the complete dataset at the time this work was being done is shown in Fig. 5, where the number of samples per class is shown after ordering the data in an increasing order; this is also a clear indication of how unbalanced the dataset is (some classes have merely a single sample), thus, how important the data augmentation becomes to balance the classes and tackle the inherent bias, even before the application of the machine learning method.

Table I. Mineral species identification results (tree-based methods in italics)

Method	Accuracy (%)
Decision Tree	*31.6*
Multilayer Perceptron	35.6
Random Forest	*67.5*
1-NN, norm	82.1
10-NN, norm	82.2
WN, sqrt+norm+sigmoid	84.8
Deep CNN (corrected data)	88.4
Random Forest P&A	*81.3*
Extra Trees P&A	*88.8*

Table II. Dana classification mineral identification results (tree-based methods in italics)

Method	Accuracy (%) Class	Type	Group	Species
Decision Tree	*44.3*	*40.5*	*37.3*	*31.6*
Multilayer Perceptron	59.0	51.9	46.0	35.6
1-NN, norm	94.9	92.9	90.7	82.1
10-NN, norm	93.8	91.7	89.9	82.2
WN, sqrt+norm+sigm.	94.8	93.3	92.0	84.8
Random Forest P&A	*86.7*	*85.3*	*83.5*	*81.3*
Extra Trees P&A	*95.7*	*94.3*	*92.5*	*88.8*

As out aim was to explore our methods performance in species classification, but also in terms of the Dana classification we conducted two sets of

[2] Random Forest is an ensemble learning method, based on the creation of multiple Decision Trees that is able to correct for Trees' inclination to overfit.

[3] The RRUFF Project website contains a database of Raman spectra, X-ray diffraction and chemistry data for minerals, http://rruff.info

experiments. The results are summarized in Tables I and II. As shown in Table I, the Extra Tree with pre-processing and augmentation (shown as P&A) outperforms all other methods, even the Deep CNN method which is computationally intensive. Simply applying Random Forest is apparently not enough, as the attained accuracy is 67.5%. On the contrary, by applying P&A prior to Random Forest, the accuracy significantly improves to 81.3%. As shown in Table II, our method outperforms all other methods that dealt with Dana classification accuracy. In this case the improvement in species identification improves up to 4%.

5. Conclusion

In this work we presented a novel method of mineral identification from Raman spectra based on a combination of off-the-shelf tools. By combining proper data pre-processing, data augmentation and ensemble learning we were able to outperform commercial software by 6.7% and state of the art approaches by 0.4% in overall or by 4% in Dana classification. The approach is of low complexity, it is scalable, and it allows for parallel implementations that can boost performance.

Acknowledgement

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EMPLOYING AGENT-BASED MODELING TO STUDY THE IMPACT OF THE THERAN ERUPTION ON THE MINOAN SOCIETY

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Περίληψη

Ο σκοπός αυτής της εργασίας είναι να εμβαθύνει την κατανόησή μας για την παρακμή του Μινωϊκού πολιτισμού, χρησιμοποιώντας ένα υπάρχον πολυπρακτορικό μοντέλο προσομοίωσης (ABM) για να μελετήσει σε ποιο βαθμό η κατακλυσμική έκρηξη του ηφαιστείου της Θήρας επηρέασε την κοινωνική εξέλιξη του Μινωϊκού πολιτισμού. Λαμβάνοντας υπόψη τη γεωργία ως κύρια παραγωγική δραστηριότητα για την διατήρηση του ανθρώπινου πληθυσμού, αξιολογούμε τις επιπτώσεις της έκρηξης του ηφαιστείου πάνω σε διαφορετικά μοντέλα κοινωνικής οργάνωσης, εστιάζοντας στην ευρύτερη περιοχή των Μαλίων της Κρήτης. Τα παραδείγματα κοινωνικής οργάνωσης που εξετάστηκαν είναι εμπνευσμένα από ένα μοντέλο αυτο-οργάνωσης μιας κοινότητας πρακτόρων καθώς και ιδέες από την εξελικτική θεωρία παιγνίων. Οι επιλογές παραμέτρων του πολυπρακτορικού μοντέλου βασίζονται σε αρχαιολογικές θεωρίες και ευρήματα, αλλά δεν είναι μεροληπτικές προς οποιαδήποτε συγκεκριμένη παραδοχή. Αποτελέσματα από διαφορετικά σενάρια προσομοίωσης επιδεικνύουν μια εντυπωσιακή βιωσιμότητα των νοικοκυριών (πρακτόρων). Ωστόσο, μερικά σενάρια οδηγούν σε αισθητές αλλαγές στην κατανομή των οικισμών, σχετιζόμενες με μια παρατηρούμενη σημαντική αύξηση των ποσοστών μετανάστευσης αμέσως μετά την έκρηξη του ηφαιστείου της Θήρας. Επιπλέον, η έκρηξη φαίνεται ότι είχε ισχυρό αντίκτυπο στην κοινωνική οργάνωση, μετατρέποντας την αρχικά συνεργατική συμπεριφορά των πρακτόρων σε μη συνεργατική. Το γεγονός αυτό παρέχει στήριξη σε αρχαιολογικές θεωρίες που δηλώνουν ότι η έκρηξη του ηφαιστείου της Θήρας οδήγησε σε μία σταδιακή (και όχι άμεση) κατάρρευση του Μινωϊκού κοινωνικο-οικονομικού συστήματος, εν μέρει λόγω συγκρούσεων στο εσωτερικό των τοπικών κοινοτήτων.

Abstract

The purpose of this work is to deepen our understanding of the Bronze Age Minoan civilization’s decline, by utilizing an existing agent-based model (ABM) to study the extent by which the cataclysmic volcanic eruption of Thera (Santorini) impacted the Minoan social evolution. Considering agriculture as the main production activity sustaining the human population, we evaluate the volcanic eruption impact on different social organization models, focusing on the wider area of Malia in the island of Crete. The social organization paradigms examined are inspired by a framework for self-organizing agent organizations, and ideas from evolutionary game theory. Model parameter choices are based on archaeological theories and finds, but are not biased towards any specific assumption. Results over a number of different simulation scenarios demonstrate an impressive sustainability of household agents. However, in some scenarios we observe noticeable changes in the settlements' distribution, relating to significantly higher migration rates immediately after the eruption. Moreover, the eruption appears to have had a strong impact on social behaviour, transforming the initially cooperative agents' behaviour to a non-cooperative one. This provides support for archaeological theories suggesting that the Theran eruption led to a gradual (and not immediate) breakdown of the Minoan socio-economic system, partly due to inner community competition and conflicts.

Λέξεις Κλειδιά/Keywords: agent-based modelling, computational archaeology, social organization, Minoan civilization

1. Introduction

Over the last 15 years archaeological simulation models are associated with a particular modelling paradigm, namely agent-based modeling (Lake 2014). Agent-based models incorporate ideas from multi-agent systems (MAS) research, mainly to enhance agent sophistication, while information processing is achieved among interaction of entities (agents) that also consider their environment, with a view to assess their effects on emergent properties of the system as a whole. Agent-based archaeological simulation can be viewed as the means of modelling long-term social change by tracing individual or collective entities and its actions, allowing us to understand the feedback between decision-making and the environment in which decisions are made (Kohler and Gumerman, 2000). Many archaeologists have commented on the coming of age for agent-based modelling in archaeology and the utility of archaeological simulation considering the degree of its methodological maturity (McGlade 2005; Lake 2015); others provide proper introduction on archaeological simulation, focusing on agent-based simulation (Railsback and Grimm, 2012). In addition, by the turn of the millennium archaeological simulation has already included considerable examples of spatial agent-based modelling, since many ABM contributions include a spatial component (Westervelt, 2002; Chliaoutakis and Chalkiadakis, 2015).

In this work, we adopt such an approach of agent-based modelling and utilize a recently developed ABM with autonomous agents, able to explore alternative hypotheses regarding the social organization of ancient societies (Chliaoutakis and Chalkiadakis, 2016). The purpose is to deepen our understanding of the Bronze Age Minoan civilization's decline by incorporating a natural disaster sub-model in order to study the extent by which the natural phenomenon affected the ancient society's social evolution. Specifically, we simulate the interactions of agents, corresponding to households in early Minoan settlements located in the Malia area at the island of Crete, for studying and evaluating the impact of the volcanic eruption of Thera on different agent social organization models. The social organization paradigms examined are inspired by a framework for self-organizing agent organizations, and ideas from evolutionary game theory (EGT). Considering agriculture as the main production activity sustaining household agents' population, we try to assess the imminent social crisis in terms of household and settlement sizes, migration behaviour and agents strategic behaviour evolution, before and after the natural disaster.

Results over a number of different simulation scenarios demonstrate an impressive sustainability of household agents, even for scenarios with relatively high mortality. At the same time, higher settlement numbers and fewer agents per settlement after the volcanic eruption are observed. Additionally, even higher migration rates are recorded immediately after the eruption. However, the serious decline in population size and change in settlement distribution patterns, appear to transform the initial cooperative agents' behaviour towards a non-cooperative one, thus, providing support to archaeological theories suggesting that the Theran eruption led to a gradual breakdown of the Minoan socio-economic system.

2. Archaeological background

Some of the most interesting questions one may ask about early societies are about people and their relations, the nature and scale of their organization, about social change and decline of past civilizations. Specifically, in this work, we attempt to incorporate natural disaster scenarios into archaeological simulations about social change, based on archaeologically traceable environmental and human impact of the mid-2nd millennium BCE Santorini eruption to the Minoan civilization.

The Theran eruption of Santorini continues to trouble scientists, especially on questions surrounding the volcanic eruption absolute date and its impact on the ecosystem of the Ancient Mediterranean. A series of changes in the Aegean, in particular in Cretan Bronze Age society, were triggered by the LM (Late Minoan) IA or ca. 16th c. BCE Santorini eruption (Driessen and Macdonald, 1997). These changes would have caused the breakdown of the Minoan system over the course of a few generations, during LM IB (15th c. BCE). Archaeologists hypothesize that the eruption would have initially caused major problems in food production and distribution, undermining central authority and leading to a process of decentralization; this fragmentation would then have led incrementally to internal conflict. However, despite the many destructions and abandonments documented, Minoan culture survived.

There is still no agreement on the absolute date of the eruption. Quite a few earth scientists take the late 17th c. BCE date (between 1630 and 1600 BCE) for granted, whereas many archaeologists remain to the traditional late 16th c. BCE date, roughly around 1530-1520 BCE (Driessen 2018). Despite the absolute date of the eruption, there is little doubt that the eruption was preceded and probably even triggered by one or more earthquakes. However, considering the archaeological record of Bronze Age Crete, careful analysıs of old and new archaeological data suggest that earthquake evidence is patchy, frequently ambiguous, and generally less spectacular than what popular accounts of Minoan society would expect (Jusseret and Sintubin, 2017).

Moreover, there is also no doubt that during the eruption large amounts of ash and pumice were emitted. Deposits of tephra originating from the Minoan Santorini eruption have been found dispersed in many Cretan sites. However, distinct volcanic ash layers are not apparent in the open hilly landscape of Crete (Bruins et al., 2008). While ash veils from a volcanic eruption normally clear up within a few years, dendrochronological work suggests limited plant growth for up to a decade (Baillie and Munro, 1988), rendering its impact detrimental to farms, at least on the eastern half of island of Crete. It may further be assumed that the eruption was accompanied by one or more tsunamis (Sakellariou et al., 2012). Tsunami generation and simulations suggest that the north coast of Crete was struck by highly variable wave amplitudes, ranging from a few to almost 30m with inundations of up to 300m inland, considering caldera collapse (Novikova et al., 2011). However, new evidence suggests that tsunamis can only have been caused by pyroclastic flows, where reasonable estimates reach up to a maximum of 10-12m height (Nomikou et al., 2016).

Based on the above, we may now form and describe the conceptual natural disaster sub-model incorporated in our ABM, in an attempt to provide insights to whether the effects of the Santorini eruption set in motion the process that led to the breakdown of Minoan society in ca. 1450 BCE.

3. The Agent-based model

In this work we incorporate a natural disaster sub-model on an existing ABM for simulating an artificial ancient society of household agents evolving within a grid environmental topology (Chliaoutakis and Chalkiadakis, 2016).

Agents and resources in the model are located within a 20 x 25 km area with a 100 x 100 m cell size for the grid space (Fig. 1). Environment's spatial information is derived from modern data concerning the topography – *i.e.*, today's elevation, slope and aquifer (rivers and springs) locations. Thus, the landscape consists of 50K cells, while the time slot investigated is 2000 years (3100 to 1100 BCE), with annual time steps.

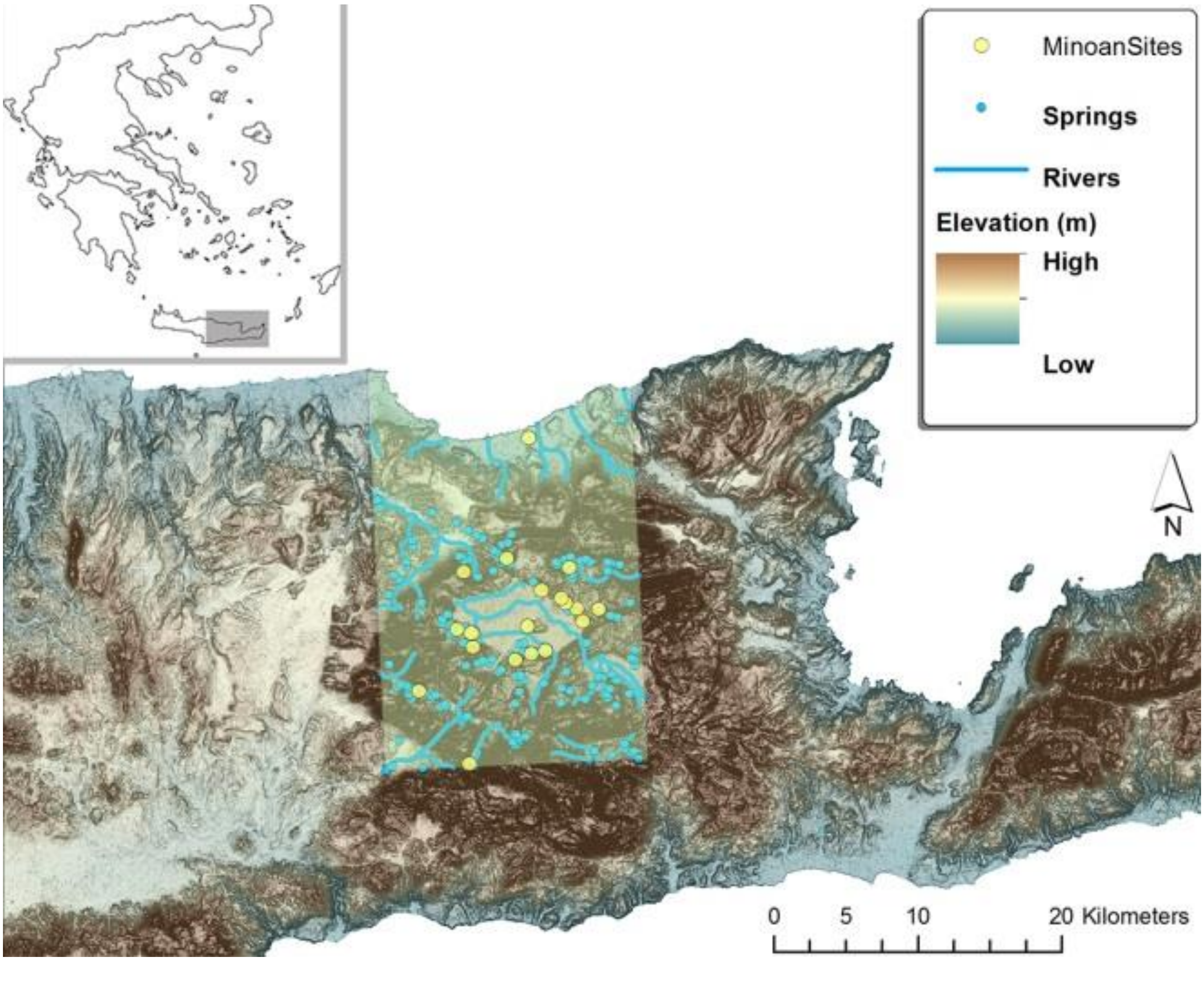

Figure 1. *Map indicating the area near Malia that was used in the ABM simulations. Environmental data included: elevation information, aquifer locations and known (Minoan) site locations.*

An agent in the model represents a household, containing up to a maximum number of individuals (inhabitants), and resides in a cell within the environmental grid, with the cell potentially shared by a number of agents. Adjacent cells occupied by agents make up a settlement — and there is at least one occupied cell in a settlement. Estimated population per hectare (cell) in an agricultural settlement was set by default to 100 based on population estimates by Isaakidou (2008). Households are *utility-based autonomous* agents who can settle (or occasionally re-settle) and cultivate nearby environmental cells. Household agents also possess an explicit representation of the environmental grid, allowing them to choose the best available location they can migrate to, in order to improve their utility. An agent moves to another location only when it finds a location within its perception radius that is better than its own location.

The agent calculates its expected utility for the new location as the average agricultural production of the neighboring cells, considering the agent moved to the respective unused cell. If the expected utility of the agent for the new location is higher than the agent's current utility, the location is considered to be an option for migration. If there are many such locations, the agent migrates to the one perceived to be the most favorable. We note, that we do not argue that utility is the main factor driving human behaviour or the advance of human societies. Nevertheless, utility theory has long been adopted as a useful tool in Artificial Intelligence (Russell and Norvig, 1995).

The total number of household agents in the system fluctuates over time, as individuals are born or die. The annual levels of births of individuals within a household are based on the amount of resources harvested and consumed by the household agent during the year. These rates produce a population growth rate of 0.1%, when households consume adequate resources (Chliaoutakis and Chalkiadakis, 2016). This assumption corresponds to estimated world-wide population growth rates during the Bronze Age (Cowgill, 1975). Resources harvested affect agent's utility, $U_x = f(population; location)$, a function inspired by the logistic map equation, the discrete version of the logistic differential equation, widely used to model population growth (Law et al., 2003). This naive function captures the fact that labour applied on a cultivated cell increases crop yield up to a point, but at the same time a household agent cannot use productively a specific location forever due to soil depletion. Cultivation area is also affected by the cell's geomorphological characteristics, i.e. as a decay of agricultural land suitability with increasing slope, given its location on the grid. Moreover, when individuals in a household exceed a critical number, new households (agent offsprings) are created; and when the agent overall utility levels are not high enough to sustain its individuals, households are "abandoned" and agents die. We refer to Chliaoutakis and Chalkiadakis (2016) for details.

Any interaction between a pair of household agents within a settlement, takes place based on their relation type: acquaintance, peer or authority (superior - subordinate) related agents; and these relations give rise to a social structure reflecting the flow of resources during exchanges among the agents. The authority relation depicts a "superior status" of an agent x over the subordinate agent y in the context of their social organization, reflecting that higher amounts of resources flow from x to y during exchanges, than those flowing in the opposite direction. The peer relation holds between agents who are considered more-or-less equal in status (i.e. flows involve resource transfers of almost equal amounts in both directions); while acquainted agents are aware of each other's presence, but have no interaction (Chliaoutakis and Chalkiadakis, 2016). Agents use the information about all their past and current year resource allocations to re-evaluate and possibly alter their relations with others. These relations determine the way resources are ultimately distributed among the agents. This re-organization stage is performed within the framework of an (extended) agent self-organization algorithm (Kota et al., 2009), that results to the continuous targeted redistribution of wealth, i.e., resources flow from the more wealthy agents to those more in need, maintaining a dynamically "stratified" social structure.

Specifically, in our simulation experiments we consider the following differentiated social organization paradigms for household agents:

Hierarchical (static): Agents distribute resources based on a fixed hierarchical social structure. The agents are linked to each other via static social relations, which determine the amount of resources each agent acquires via the distribution scheme. In short, there is no re-organization stage.

Self-Organization (dynamic): Agents autonomously re-arrange their relations, and hence the underlying social (network) structure describing these relations, without any external control. They do so in order to adapt to changes in requirements and environmental conditions. They constantly re-evaluate and possibly alter their relations with other agents, employing the aforementioned self-organization algorithm.

Evolutionary self-organization: Each household agent is "genetically" programmed to play originally some pure strategy and agent offsprings inherit the strategy the agent currently plays. An agent playing repeated stage games with opponents, sticks to some pure strategy for some period consisting of several years, and then reviews its strategy, which sometimes results in a change of strategy. We assume three simple player strategic behaviours: a cooperative one (C), willing to share resources with another player; a “defection” one (D), refusing to share resources; and one which starts with cooperation and then behaves as the other player did in the previous game round, namely Tit-for-Tat (Axelrod and Hamilton, 1981). Considering these different strategic agent types as playing games against each other, we explore the evolutionary dynamics that arise. Agents’ payoff is interpreted as fitness, depending on the relative proportions of the different strategies in the population. Success in game playing improves utility, and is translated into reproductive success; strategic agents that do well over time reproduce more, while the ones that do poorly are outcompeted. As such, self-organization is now driven by the interactions of strategic agents operating within a given social organization group and the replication mechanism is based on imitation and reinforcement of successful behaviours (Chliaoutakis and Chalkiadakis, 2017).

The above agent behaviours are evaluated before and after the natural catastrophe, to assess the social crisis in terms of household and settlement sizes, social structure adaptation to environmental changes, migration rates and strategic behaviour evolution.

3.a The natural disaster sub-model

We assume that the natural disaster sub-model takes effect at 1630 BCE, that is, approximately the date of the eruption estimated by earth scientists (Driessen 2018). In order to conceptualize the model, we considered tsunami and volcanic ash impact on the artificial society and their effects on agriculture and human life. To that end, we assume the following simple processes based on archaeological estimates (cf. section 1):

Tsunami: We assume a 10 meters sea-level rise (including 2m rise on today elevation), with inundations of 300 meters inland in order to define tsunami affected areas on the model’s environmental grid. The agricultural impact to the respective areas is assumed to be rendering associated agricultural fields useless for up to 20 years. Human (immediate) impact is also assumed to create 10-15% fatalities (mortality) at the tsunami affected areas, linearly decreasing with distance to coastline.

Volcanic ash: Considering that the volcanic ash layer is smaller at higher elevations and clears up within 2-3 years, we assume the environmental impact of the eruption to be a limited growth to all agricultural fields in the model area for up to 10 years. The agricultural impact is considered to affect environmental cells inversely linear to elevation. For simplicity, no immediate human impact is assumed by the volcanic ash emission process.

The above simple natural disaster model is incorporated to the aforementioned ABM for studying and evaluating the impact of the volcanic eruption of Thera on different social organization paradigms of Minoan household agents located in the wider area of Malia at the island of Crete (see Fig. 1).

4. Simulation experiments and results

Model parameters were initialized to values that correspond to archaeological records or estimates found in archaeological studies relevant to the period of concern, such as estimated per hectare population in an agricultural settlement, resources amount required per individual per year, agricultural strategy and production per year, etc. (Isaakidou, 2008; Bevan, 2010). The number of initial settlements per scenario was set to 2, and the number of household agents in a given settlement was initialized to a random number between 1 and 10.[1] Moreover, a cell’s initial resources amount at a given run is multiplied with a sample from a standard normal distribution, and thus varies across runs. In all simulation experiments below, an intensive agricultural regime is employed, and it is required that settlements are built near aquifer locations. Mortality rates for the natural disaster sub-model – that is, the probability of annual deaths among the individuals located at the tsunami-affected area – were initialized to 10% and 15%.

Furthermore, the random number generators introduced in parts of the model are obviously “pseudo-random”. Thus, via using the same random “seeds”, one may introduce the same opportunities for agents in the model simulations (i.e., same “random” initial agent locations etc.). In this way, our simulations are reproducible.[2] In our base experiments, we evaluate the performance of agents that use self-organization against those that self-organize but do not change their relations (hierarchical), in terms of population growth achieved. In total, 12 experimental scenarios were simulated, and each scenario was simulated for 30 runs, for a total of 360 simulation runs = 30 x 2 (agent organization paradigms) x 3 (volcanic eruption scenarios) x 2 (mortality rates). In figures below, we depict shaded areas that correspond to

[1] We further experiment with 20 settlements; however, their initial number in the ABM simulations does not change substantially the conclusions drawn from the simulation results (Chliaoutakis and Chalkiadakis, 2016).

[2] The source code will be available at http://www.intelligence.tuc.gr/~angelos upon publication.

95% confidence intervals around lines corresponding to average number of household agents, number of settlements and settlement sizes.

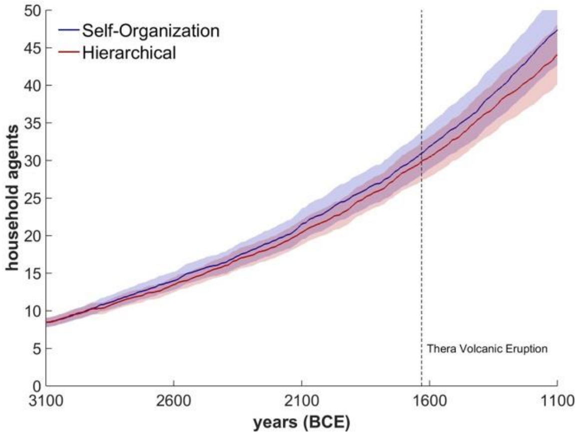

Figure 2. Number of household agents over 2000 (yearly) time-steps for the default scenario, considering 10% mortality rate.

Thus, in our default volcanic eruption scenario, we report that agent population size (number of households) increases with time, regardless of mortality rates, exhibiting similar viability potential for both the self-organization and hierarchical organization structures (Fig. 2). Additionally, we observe no human losses; during simulation runs, no household agent was settled at tsunami-affected areas at the time of the eruption, where fatalities are introduced by the model.

We do observe, however, an increase of ~60% on the average number of settlements (Fig. 3). This is due to higher migration rates observed immediately after the eruption, as further stated in our observations.

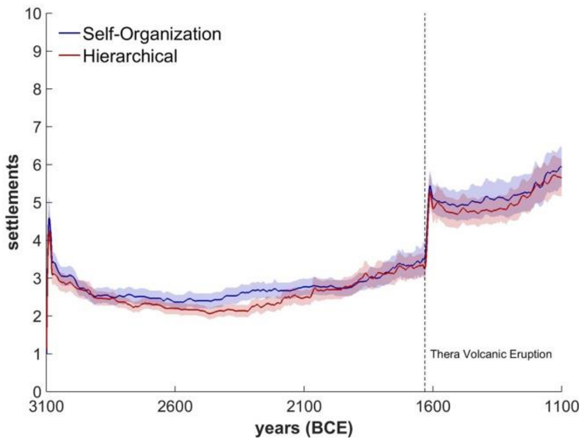

Figure 3. Number of settlements over 2000 (yearly) time-steps for the default scenario, considering 10% mortality rate.

Moreover, we report an overall decline of ~30% on the average number of household agents per settlement after the eruption (Fig. 4). Therefore, changes in settlement numbers and sizes are observed due to the agricultural impact of the eruption; more and smaller size settlements continue to cultivate the land after the eruption. Intuitively, one could assume that the layering of volcanic ash and the subsequent degradation of soil quality led to increased migration.

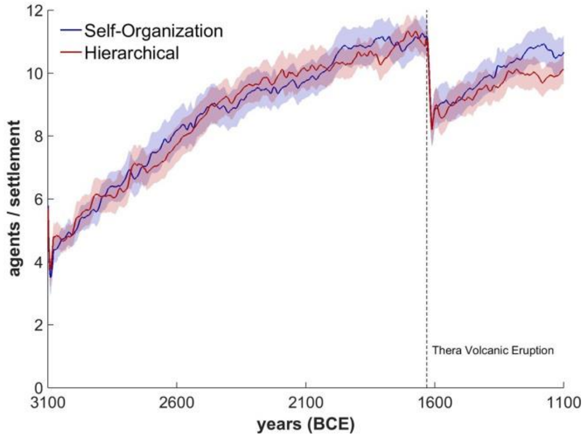

Figure 4. Number of agents per settlement over 2000 (yearly) time-steps for the default scenario, considering 10% mortality rate.

Since no human losses were observed to the default volcanic eruption scenario, we attempted to manually “move” (set) at the time of the eruption existing agent settlements to tsunami affected areas, in order to model human fatalities. We assumed the following two alternative scenarios: (i) moving the closest existing settlement to the geographical location of the archaeological site of Malia; and (ii) moving two closest existing settlements to randomly selected tsunami affected geographical locations.

In what follows, we refer to the former scenario (i) as scenario A, where the impact of the tsunami waves at the archaeological settlement of Malia presupposes an unrealistic parameterization to the natural disaster sub-model: the site is located in an elevation of 18m (wave height) and a distance from the coast 670m (inundation). We also refer to scenario (ii) as scenario B, where the default parameterization of the natural disaster sub-model was used. Simulation results of both scenarios exhibit similar effects; nevertheless, those are more intense and noticeable in the case of scenario B.

Specifically, the household agents’ population size is now reduced, for both the self-organization and hierarchical organization structures, reaching up to ~8% death toll for scenario A and up to ~16% for the scenario B, respectively (Fig. 5). This is due the fact that 2 out of 3 settlements on average (over 30 runs) were struck by the tsunami waves.

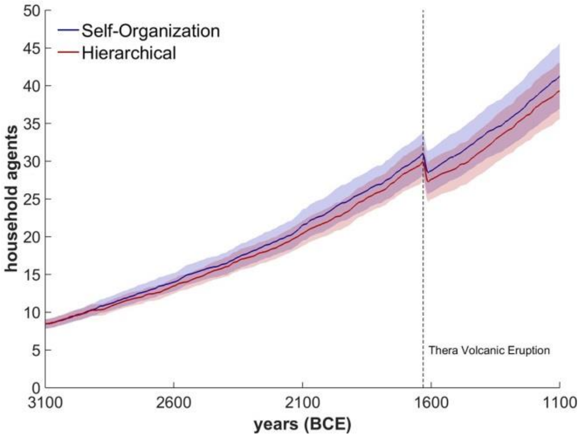

Figure 5. Number of agents over 2000 (yearly) time-steps for scenario B, considering 15% mortality rate.

However, we observe an increase on the average number of settlements, of ~90% for scenario A and of ~150% for scenario B, respectively. The latter is shown in Fig. 6.

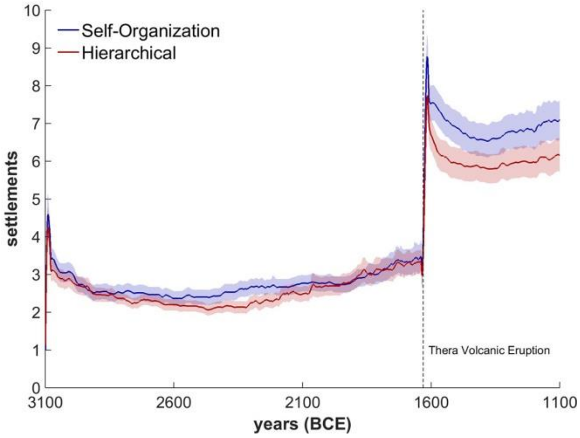

Figure 6. Number of settlements over 2000 (yearly) time-steps for scenario B, considering 15% mortality rate.

Moreover, we observe more settlements after the volcanic eruption for household agents adopting the self-organized social behaviour, rather than the hierarchical (static) one.

In addition, we observe an even more abrupt decline on the average number of household agents per settlement (settlement size) after the eruption, of ~40% for scenario A (Fig. 7) and of ~55% for scenario B (Fig. 8), respectively. Therefore, we observe a totally changed landscape consisting of many "small-size" settlements after the eruption rather than a few and higher in size communities before the eruption. This major change is a result of the environmental impact by the volcanic ash and pumice, as well as the human impact attributed to the tsunami waves that struck settlements located near to the coast. This is because of "forced" migration due to soil degradation. We report that before the eruption, migration rate for the agents – that is, average number of households out of the total of households that migrate annually to other locations – was ~1%, while immediately after the eruption migration rate was increased to ~15%, ~20% and ~25% for the default, A, and B scenarios respectively.

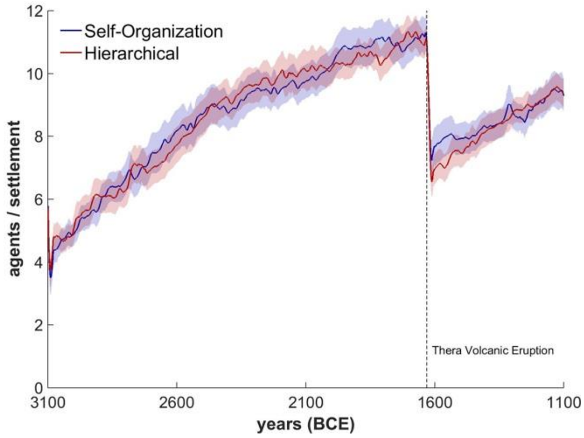

Figure 7. Number of agents per settlements over 2000 (yearly) time-steps for scenario A, considering 15% mortality rate.

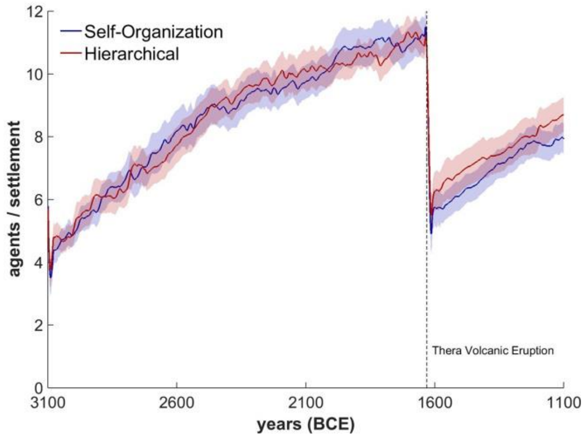

Figure 8. Number of agents per settlements over 2000 (yearly) time-steps for scenario B, considering 15% mortality rate.

Higher migration rates are the result of the high number of household agents being undernourished: immediately after the eruption, about 70% of household agents are below their utility threshold, a fact which means that the agents possess insufficient resources for sustaining themselves.

Since household agents are able to store any surplus resources in their storage, for up to several years (default: 5), we report on the average amount of resources stored before and after the time of the eruption, in order to further examine the high migration rates and percentage of household agents being undernourished. The average amount of resources stored by household agents during the simulation period is similar for all scenarios, however, agents adopting the self-organized social behaviour appear to have an advantage on the amounts they were able to store after the volcanic eruption. Storage average values drop to ~95% immediately after the time of the eruption; however, self-organizing strategies succeed to store even more than before the eruption, after a few decades from the time of the eruption until the end of the Minoan period, while hierarchically organized agents also manage to bounce back in terms of food stored (Fig. 9). Moreover, we observe that after the eruption, storage values are higher for agents adopting a self-organization social behaviour than agents employing a static hierarchical social paradigm.

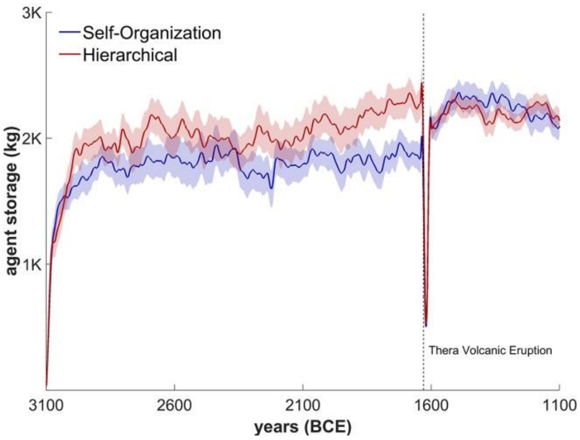

Figure 9. Agent storage over 2000 (yearly) time-steps for scenario B, considering 15% mortality rate.

Certainly, the impact of a natural disaster on a human society tends to affect also aspects of its community life, since essential functions of the society (such as the allocation of resources) are interrupted or destroyed. Therefore, in order to assess the social crisis potentially caused by the volcanic eruption impact, we also provide results on an alternative agent self-organization social paradigm that is driven by the interactions of strategic agents operating within a given social organization group, namely *evolutionary* self-organization.

Thus, we simulated 6 additional experimental scenarios, where each scenario was simulated for 30 runs, for a total of 180 simulation runs, considering all three social organization paradigms and mortality rates of 10% and 15%. However, the number of initial settlements per scenario was now set to 20. In this way the evolution of strategic agents' behaviour during the simulation can be better observed. To this end, we evaluate the performance of agents that play games and self-organize, in terms of population growth achieved.

In particular, we examine the evolutionary self-organization social behaviour setting that was able to achieve the most cooperative behaviour observed. In previous work, we have shown that agent populations converge to adopting cooperative strategies, despite this behaviour being in contrast to that prescribed by the stage game Nash equilibrium. In particular, cooperative behaviour was more widespread when agent fitness was evaluated with respect to their overall utility rather than their immediate reward, and the adoption of alternative strategies was stochastic (Chliaoutakis and Chalkiadakis, 2017)

The viability results are similar with the previous ones. This is because of the migration due to soil degradation. The intuition and conclusions drawn from the previous results do not change. Interestingly, however, we observe that the average number of household agents adopting a defective behaviour D after the eruption is increased and exceeds those that adopt a cooperative one (Fig. 10).

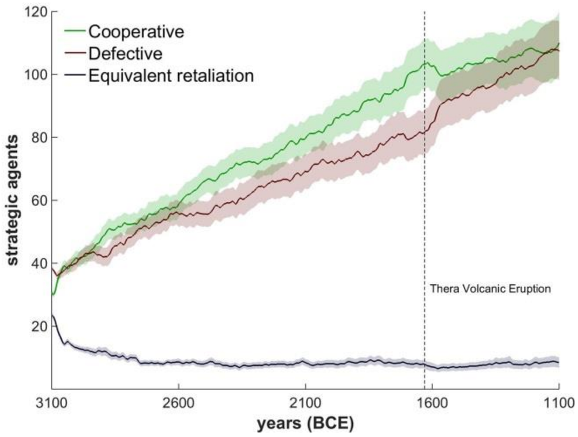

Figure 10. Strategic agent population over 2000 (yearly) time-steps for the default scenario, considering 15% mortality rate.

This indicates that the eruption also had a strong impact on the social behaviour of the household communities. This observation is in line with the fact that conflict usually arises due to problems with the allocation of resources for rehabilitation after a disaster, given its impact on natural resources (Driessen 2018).

5. Conclusions and future work

In this work, we attempted to deepen our understanding of the Bronze Age Minoan civilization's decline by incorporating natural disaster scenarios in an ABM for archaeological simulations. Specifically, we explored whether the Minoan eruption of the Thera volcano was a catalyst, through its environmental and human impact, which triggered a disintegration process in early Minoan communities. Household agents were assumed to be located in Malia area at the island of Crete, and different (household) agent social organization paradigms are employed, inspired by MAS and EGT, and in particular, a framework for self-organizing agent organization. We tried to assess the imminent social crisis in terms of household and settlement sizes, migration behaviour, and evolution of agent strategic behaviour, before and after the eruption.

Simulation results over a number of different scenarios show higher non-cooperative household agent numbers after the eruption. This result may provide support to archaeological hypotheses of decentralization, which led to political fragmentation and internal conflict with increasing competition, largely related to the acquisition of resources (Driessen and Macdonald, 1997).

Moreover, we observed a significant change in settlement distribution patterns, an effect of high mobility and starvation rates, rendering a landscape with higher number of "small-size" settlements at the end of the LM IB period. Archaeologists argue that the number of settlements or households, of ritual sites and of funerary sites that were abandoned during LM IA is considerable, however, they cannot yet distinguish archaeologically between a mature (i.e. prior the eruption) and final (i.e. contemporary to the eruption) abandonment (Driessen, 2018). Interestingly, in our simulations increased food storage is also observed after the eruption, suggesting collection of resources organized on a greater scale. Surprisingly, recent excavations have brought evidence pinpointing towards an increase in storage space in the mature LM IB phase, while the reduction in population size, change in the distribution of human groups, including their mobility patterns, and the conversion of food into direct and indirect storage, are all features evidenced during LM IB (Driessen and Macdonald, 1997). Therefore, results may provide support to archaeological hypotheses suggesting that the Theran eruption led to a gradual breakdown of the pre-eruption Minoan socio-economic system.

In terms of future work, we need to enhance the ABM with additional geomorphological information and archaeological evidence of interest. In addition, we intend to examine and incorporate further models of exchange for inter-settlement trading behaviour; and potentially address other specific archaeological questions and gain new insights into existing theories. The use of our agent-based model bears the potential of assisting archaeologists to come up with entirely novel explanations and paradigms regarding the ancient society being studied.

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